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ORIGINAL ARTICLES.

Mangaia and Rurutu—a Comparison between two Pacific Islands.

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IN an article with the above heading (GEOL. MAG., Vol. LXIV, 1927, p. 518) Mr. L. J. Chubb discussed the geology of these two small Pacific islands, which are somewhat centrally situated in the western part of the South Pacific Ocean.

With nearly all the details of the comparison that he makes I cordially agree, for the two islands are similar in their main features of central volcanic plateau, with a marginal ring of varied coral reef limestone (makatea) elevated 200 feet—more or less—and finally a fringing living reef at the sea-level.[1]

The differences between the islands are found in the mountainous elevation on the plateau in Rurutu, while in Mangaia the level of the surface of the plateau is not interrupted. Again in Mangaia, as shown in the map (Fig. 1), the raised coral limestone forms a complete ring separated from the volcanic area by a series of swampy flats, but little above sea-level—though in four places spurs from the volcanic hill run with even grade to the surface of the makatea. In Rurutu for the greater part the volcanic ground slopes directly on to the top of the limestone ring, except in the south-east, where the Paparai Valley runs parallel to the coast between the volcanic rock and the makatea.

The drainage of the Paparai Valley and of that portion of the volcanic hill from which the run-off flows into it, passes to the sea through subterranean channels in the makatea. In Mangaia Island and in Atiu Island (Fig. 2), 100 miles to the north, all of the island drainage reaches the sea in that manner.

It is in regard to the origin of the two flats in Mangaia and Atiu and of the similar depression of the Paparai valley of Rurutu, that I differ from Mr. Chubb. My knowledge of Mangaia and Atiu has been gained from two months' stay on each of these islands, studying them as a Research Fellow of the Bishop Museum, Honolulu.

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[1] P. Marshall, "Geology of Mangaia," *Bishop Mus. Bull.*, 36, Honolulu, 1927.

My explanation of the origin of these swampy areas is that they are the sites of old lagoons lying between a small barrier reef of earlier ages and the coast of the island. Such structures are believed to have been formed in accordance with Darwin's theory during a period of subsidence, of which the great thickness of the makatea itself is a proof.

It is, however, suggested by Mr. Chubb that in Rurutu Island the depression of the Paparai Valley has been formed by erosion of the makatea by a stream which at one time ran along the junction of the volcanic rock and makatea. By the ordinary process of escarpment recession this would gradually form the depression and the cliff on the inner side of the makatea.

While I cannot discuss the Rurutu structure, as I have never visited the island, I would remark that it seems reasonable to suppose that these marginal depressions in the three islands have been formed in the same manner. In Mangaia there is a beetling cliff, in places 200 feet high, on the landward side of the makatea, and it is continuous except at four points for the whole circuit of the island. In Atiu Island there is no abrupt cliff on the inner side of the makatea, but its surface rises in a moderate slope from the swamp level to a height of about 50 feet above it in a distance of 400 yards. Inland of the swamp edge no limestone is seen. In many parts of the south of the island the swampy area is represented by a very narrow depression between the volcanic rock and the makatea.

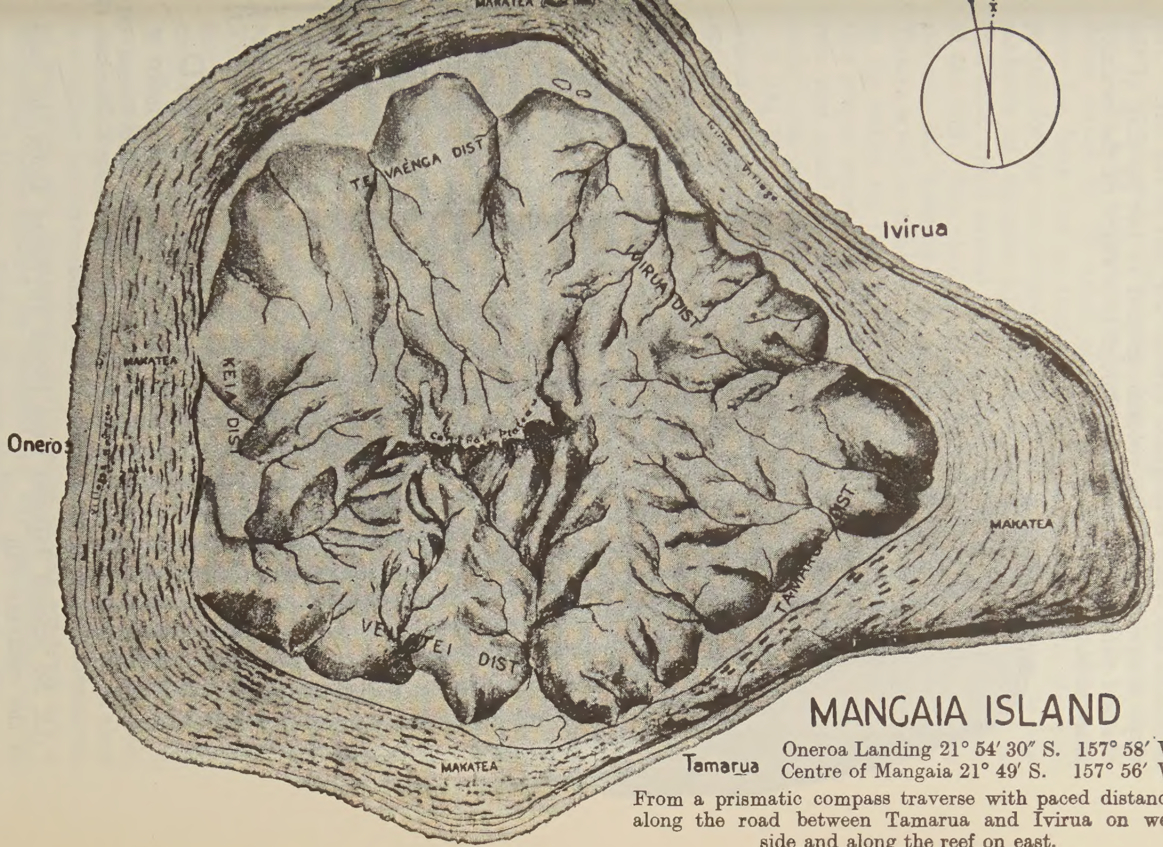
In Rurutu Island over the greater part of the circuit the makatea is directly connected with the volcanic ground. It is in the Paparai valley alone that the makatea and volcanic ground are separated by an intervening depression. Except in this valley the outward-flowing streams pass over the surface of the makatea, in which they have cut deep gorges.

If the sub-marginal depressions of these islands had been formed by recession of escarpments the following lines of evidence should be available :—

1. Stream flow along the base of the makatea cliff as shown by :
   (*a*) Definite slope.
   (*b*) Stream deposits at base of cliff.
   (*c*) Undercutting of cliffs.
   (*d*) Boulders at base of cliff.
2. Deep recesses to the entrance of the underground channels.
3. Tracts where the limestone remained in contact with the volcanic rock.

In regard to these lines of evidence the following comments may be made :—

1*a*. There is no distinct slope of such a nature as to suggest



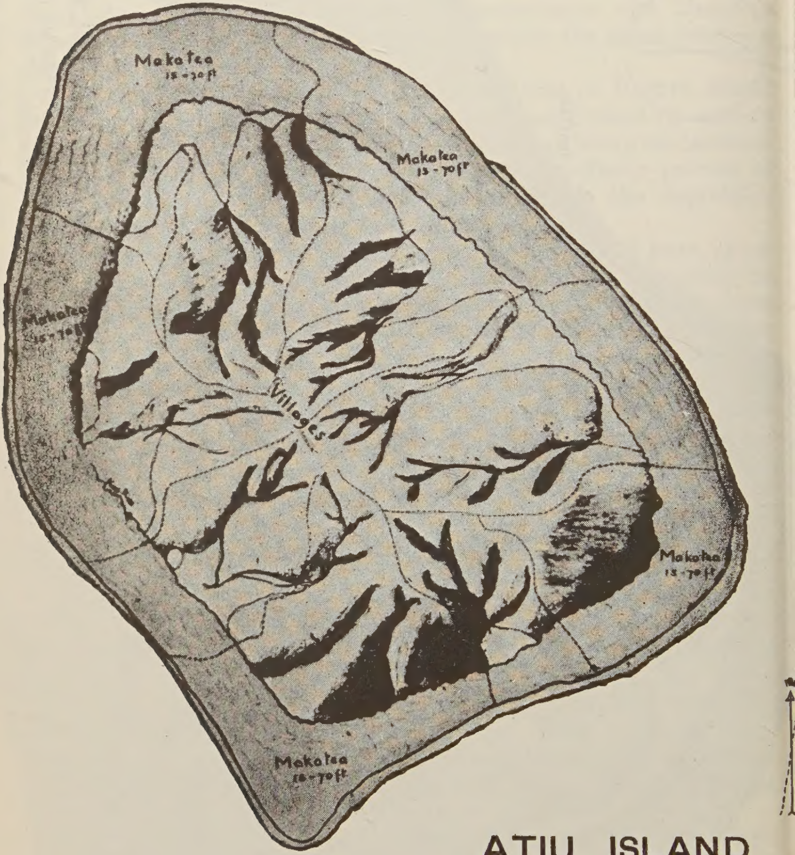
MANGAIA ISLAND

Oneroa Landing 21° 54′ 30″ S. 157° 58′ W.
Centre of Mangaia 21° 49′ S. 157° 56′ W.

From a prismatic compass traverse with paced distances along the road between Tamarua and Ivirua on west side and along the reef on east.

Fig. 1.—Map of Mangaia Island. By P. Marshall, M.A., D.Sc., F.R.G.S., Pres. N.Z. Inst. 1924. Native Names by Mama Akaui.

that a stream flowed along the base of the makatea. Over long distances the water is stagnant against the foot of the cliff. The slope is always from the volcanic ground to the opening of the channel through the makatea, though it is slight in the swampy alluvial flats.



ATIU ISLAND

Lat. 20° 02′ S. Long. 158·07 W.
Outline Surveyed by H. M. Connal, 191
Physiographic features by P. Marshall, 1

Fig. 2.—Map of Atiu Island.

1*b*. No stream deposits were found anywhere along the base of the makatea cliff.

1*c*. The cliffs are seldom undercut and then very slightly.

1*d*. The face of the makatea cliff is extremely regular. Boulders were seldom found at its base.

2. There are no deep recesses where streams enter the makatea channels. There are in places caves with a wide opening, as at Lake Tiriara and at Tamorna, but it cannot be said that these are at the head of deep embayments of the makatea cliff. One is much struck by the small amount of erosion due to the water that has been flowing through these passages since the Miocene period, for the occurrence of *Lepidocyclina* gives this age to the makatea of Mangaia island. Often the entrance is through a sink-hole, which cannot be seen until one actually reaches the foot of the cliff. The channel through which the water of the largest stream—the Taurongakakaia—flows after passing through Lake Tiriara is still so small and intricate that it has never been followed to its outlet on the reef, a distance of 400 yards. It is for this reason among others that I wrote " the ordinary action of rain and small streams can have but little effect on raised coral rock ", loc. cit., p. 44.

3. On Mangaia and on Atiu I failed to find places where the limestone remained in contact with volcanic rock, except at those spots where the spurs abut against the makatea, and here the contact was at the ends of the spurs only. On Rurutu Island this contact extends over considerable distances, and streams run straight from the volcanic ground on to the makatea into which they have cut deep gorges, a condition found also at Christmas Island in the Indian Ocean, e.g. Sydney's Dale : " This valley is one of several which, beginning at a height of between 400 and 500 feet, runs down to the sea in a generally south-west direction."[1] It would thus appear that in those islands where the makatea may be regarded as an old fringing reef the streams run straight off the volcanic rock into gorges in the makatea.

Detailed descriptions of islands with an encircling ring of makatea are few. Neither Darwin, Dana, nor Agassiz deal with any satisfactory examples. All are concerned with details of the living reefs. Mango Island of the Fiji group has been described in rather greater detail by E. C. Andrews.[2] Here the makatea is everywhere in contact with the volcanic rock, though of Miocene age. The makatea does not rise steeply on the landward side. The only stream (Rewa) shown on the map flows straight on to the surface of the makatea into which it plunges down a crevice when close to the coast.

I therefore see no reason to depart from the opinion previously expressed that the makatea which forms a ring round the volcanic core of Mangaia Island (to which I would now add Atiu Island also) is a former barrier reef. If this is accepted a number of movements of elevation and depression or of change in the sea-level are a necessary consequence as detailed in my description of the geology of Mangaia, *Bishop Museum Bulletin* 36.

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[1] C. W. Andrews, "Christmas Island," *British Mus. Monograph*, 1900, p. 283.

[2] E. C. Andrews, "Notes on the Limestones and General Geology of the Fiji Islands," *Bull. Mus. Comp. Zool. Harvard*, vol. 38, 1900, p. 18, pl. 1.

Some New Occurrences of Authigenic Potash Felspar.

By Doris L. Reynolds, M.Sc.

(PLATE XII.)

1. Introduction.
2. Authigenic Felspar in—
    - (A) Triassic Sandstone.
        - (*a*) Crystal form and optical characters.
        - (*b*) Chemical composition.
        - (*c*) Specific Gravity.
        - (*d*) Comparison with Felspars in Igneous Rocks.
    - (B) Keuper Marl.
    - (C) Dolomitic Conglomerate.
    - (D) Magnesian Limestone.
3. Comparison with other Occurrences.
4. Origin.

I. INTRODUCTION.

WHILST examining the Triassic sandstone of north-east Ireland, microscopic crystals of an authigenic mineral were found, in considerable quantities, in the sandstone from Benbradagh Hill, near Dungiven (Co. Londonderry). Mention has been made of this occurrence[1] and the mineral was provisionally assigned to orthoclase.

Subsequent examination, however, has shown it to be allied to anorthoclase and microcline, whilst further investigations have revealed the presence of similar authigenic felspar in other rocks.

2. AUTHIGENIC FELSPAR IN TRIASSIC SANDSTONE.

The mineral is most easily separated from the sandstone by pounding the rock to a sand, boiling it in HCl to free it from iron staining, washing, and collecting the fine silt which remains in suspension. This consists of chips of quartz and orthoclase, the latter sometimes kaolinized, together with well formed, perfectly fresh, authigenic felspar. A further separation can be made, after drying, by sliding the silt over a sheet of glass to which the authigenic felspar clings.

(*a*) *Crystal Form and Optical Characters.*

The crystals, thus obtained, average ·03 mm. by ·02 mm. by ·01 mm. They are of two types, the majority closely resemble rhombohedra, whilst the remainder are lath shaped. The rhomb-shape results from a combination of the forms $\{110\}$ $\{001\}$, the faces of which are sometimes equally developed, although the crystals are often tabular parallel to (001). The averages of thirty measurements show the plane angles on the faces to be 67° and 113° on (001) and 76° and 104° on (110). These angles agree with the plane angles, on similar faces, for orthoclase. Occasionally $\{010\}$ is developed, in which case the basal plane is bounded by six edges and elongated parallel to the edge (010)(001). The larger crystals flattened parallel to (001), measure ·044 mm. by ·032 mm. along the diameters on (001) and average ·018 in thickness. Crystals only half this size are not uncommon.

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[1] D. L. Reynolds, "The Petrography of the Triassic Sandstone of North-east Ireland," Geol. Mag., 1928, pp. 454–5.

The refractive indices are so near to that of Canada balsam that it is advisable to mount the crystals in water. The majority come to rest on (001), but by gently tapping the coverslip they can be adjusted to lie on any face or edge desired. With such rotation, and examination between crossed nicols, it has been found that the maximum birefringence is exhibited, when the crystals rest on (001), and consequently it may be inferred that the optic axial plane approximates to parallelism with this face. The optical orientation on (001) is illustrated in Fig. 2, and $\alpha = 1{\cdot}518$, $\gamma = 1{\cdot}524$, $\gamma - \alpha = {\cdot}006$ (determined with a graduated wedge).

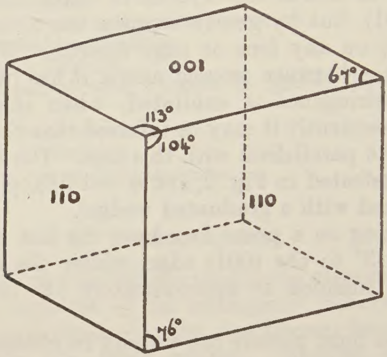
Crystals resting on a prism face have the fast ray vibrating at an angle of 2° or 3° to the (001) edge, whilst the slow ray vibrates in a direction inclined at approximately 12° to the prism edge. (See Fig. 3.)

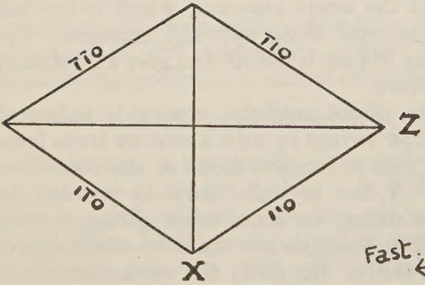
A convergent light picture can usually be obtained, both on (001) and (110). On (001) the optic normal section, the isogyres come in from the sides very rapidly, darken the field, and immediately disappear in the direction of the acute bisectrix, which is the fast ray vibration direction, the mineral being optically negative. The prism faces are inclined to the obtuse bisectrix and give an optically positive convergent light picture.

Between crossed nicols, in direct sunlight, zoning is indicated by the extinction. The shadow swings in with a convex front from opposite edges and retreats with a concave front to the other two edges. In addition, many of the crystals show in patches an exceedingly fine lamellar twinning, in some cases giving a cross hatched appearance. The albite lamellae are the more easily distinguished, both on (001) and (110). On (001) the extinction angle between the albite twin lamellae measures 8° or 10°.

All these characters clearly indicate that the mineral is a felspar, resembling orthoclase in form, and closely allied to it in optical orientation. The fine patchy lamellar twinning resembles that of anorthoclase or microcline, the extinction angle between the albite lamellae on (001) suggesting the former rather than the latter. This idea is borne out by the fact that on (110) the fast ray vibrates nearly parallel to the edge (001)(110), showing that an optic axis emerges in the angle between the direction of X and the normal to the prism face, or in other words, the optic axial angle is less than the prism angle, which is by calculation approximately 61°, a case which obtains in anorthoclase, but not in microcline or orthoclase.

The lath-like forms, which have an average size of ·06 mm. by ·02 mm. show a development of faces similar to the crystals already described, but are elongated parallel to the *c* axis. There is fine lamellar twinning parallel to the prism edge, similar to that shown by the rhombs. In addition, the great majority exhibit penetration Carlsbad twinning, the composition plane being (010). Sometimes the two individuals are quite distinct, whilst at others they are almost completely intergrown, so that only the V-shaped termination and centre groove remain to indicate the character of the twin. When mounted in Canada balsam, the Carlsbad twins rest on a prism face, and the extinction angle measured between the two halves of the twin is 25°.





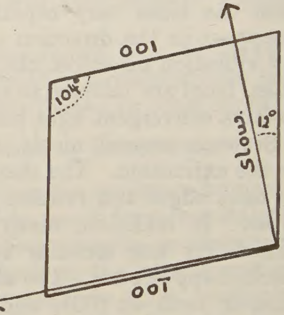


FIG. 1.—A rhomb-shaped crystal.
FIG. 2.—Optical orientation on (001).
FIG. 3.—Optical orientation on (110).

In the smallest forms of the type the birefringence is so feeble that it is impossible to distinguish between the twin halves, and the crystals give the impression of showing straight extinction, with the slow and fast rays vibrating parallel to the length and breadth respectively.

(*b*) *Chemical Composition.*

Only microchemical tests could be made, since it is not possible to obtain sufficient pure material for a chemical analysis. The crystals were dissolved in hydrofluoric acid (the only acid in which they are soluble) and left to evaporate. After recrystallization in water, crystals of potassium hydrofluosilicate and sodium hydrofluosilicate were easily distinguished, the former being by far the more abundant. Sulphuric acid was then added, allowed to evaporate, and the residue dissolved in water. A grain of caesium chloride was placed in the drop, and after evaporation colourless octahedra of caesium alum crystallized out, indicating the presence of aluminium. These tests therefore strengthen the view that the mineral is a potash soda felspar, although soda is not present in so great an amount as one would expect in anorthoclase.

(*c*) *Specific Gravity.*

An attempt was made to determine the specific gravity of the mineral by flotation in potassium mercuric iodide. All crystals floated at 2·58 and sank at 2·50, an equal separation being attained at 2·54.

(*d*) *Comparison with Felspars in Igneous Rocks.*

It should be noted that although this authigenic mineral is undoubtedly a felspar, it does not exactly resemble any species recorded from igneous rocks. Its optical characters are those of anorthoclase, but in the excess of potash over soda it is more nearly allied to microcline, whilst its S.G. is lower than that recorded for any felspar. It exhibits the characteristic freshness of authigenic felspar.

B. AUTHIGENIC FELSPAR IN THE KEUPER MARL.

An unknown argillaceous mineral, which occurs as minute laths and aggregates, has been recorded by Bosworth,[1] from the Keuper marl around Charnwood. His description of the mineral suggests a similarity to the lath-shaped authigenic felspar described above, and in consequence specimens of Leicestershire marl have been examined, and the writer is indebted to Mr. H. H. Gregory for samples of marl from Croft quarry and Bardon Hill.

These samples were powdered, boiled in HCl, and graded by water settling. Minute laths and, more rarely, rhomb-like forms, similar to those described from the sandstone, are present in the finer sediment. The laths in these samples, however, do not form so large a proportion of the rock as found by Bosworth. The larger laths measure ·004 mm. in length and show the V-shaped terminations of Carlsbad twins, whilst a shadow-like extinction can occasionally be discerned. Normally, however, the extinction appears straight, as in the smallest lath-like forms from the Benbradagh sandstone. The average refractive index is 1·52 and the double refraction low (not very high as recorded by Bosworth). The fast and slow rays vibrate parallel to the width and length of the laths respectively.

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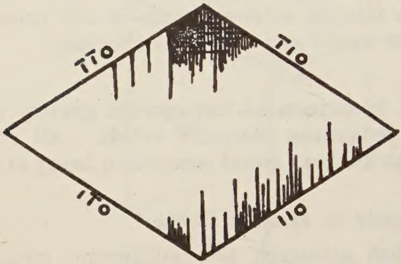
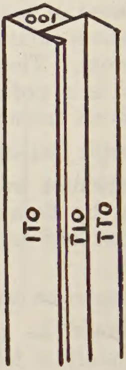
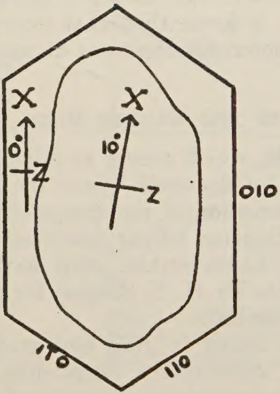
[1] T. O. Bosworth, "The Keuper Marls around Charnwood," *Leicester Lit. and Phil. Soc.*, 1911, pp. 82–9.

Most of the " rhombs " rest on a prism face and they are usually too small for the vibration directions to be determined, an average " rhomb " measuring only ·002 mm. in diameter. When large enough to exhibit birefringence, however, the vibration directions agree with those of the similar forms in the sandstone.







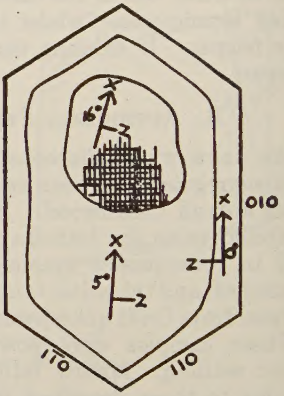


Fig. 4.—Lamellar twinning shown on (001).
Fig. 5.—Carlsbad twin showing V-shaped termination and centre groove.
Fig. 6.—Zoning and optical orientation on (001).
Fig. 7.—Zoning, optical orientation and lamellar twinning on (001), shown by a crystal from the Magnesian limestone.

Bosworth[1] gives an analysis of the fine powder from the marl which remained more than 10 minutes in suspension in water, and which he believed to consist almost entirely of the " argillaceous mineral ". The analysis, however, is undoubtedly of impure material.

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[1] T. O. Bosworth, op. cit., pp. 87, 88.

Similar minute lath and rhomb-shaped crystals occur sparsely in the Keuper marl of the Belfast district. The rhombs rest on (110) as in the Leicestershire marl.

C. AUTHIGENIC FELSPAR FROM THE DOLOMITIC CONGLOMERATE.

Lath and rhomb-shaped felspars also occur in the matrix of the Dolomitic Conglomerate from near Wells. The laths average ·008 mm. by ·003 mm., whilst the rarer " rhombs " are sometimes ·004 mm. in diameter, though usually smaller.

D. AUTHIGENIC FELSPAR FROM THE MAGNESIAN LIMESTONE.

Samples of Magnesian limestone from Roker (Sunderland), treated with HCl, give a residue consisting of detrital quartz, felspar, and rarer heavy minerals, such as tourmaline and zircon, occasional glauconite grains, a small amount of fine argillaceous material, and, in addition, rare but perfectly formed crystals of authigenic felspar. These crystals average ·052 mm. by ·032 mm., and occasionally enclose minute grains of calcite. They differ from those previously described in greater variety of form and the type of zoning they exhibit.

The following forms, recorded in order of frequency, are present :—

1.	{001} {010} {110}	tabular parallel to (001) and elongated parallel to *a*.
2.	{110} {001}	tabular parallel to (001).
3.	{110} {001}	elongated parallel to *c*.
4.	{001} {010} {110} {101}	tabular parallel to (010).

When the crystals rest on (001) a centre zone, exhibiting oblique extinction at an angle of 10° to 12° with the edge (001) (010), can be distinguished, and an outer zone showing approximately straight extinction. The boundary between the zones is usually irregular, but approaches oval (see Fig. 6). The two zones are further distinguished by the fact that the outer zone shows both a lower refraction and birefringence than the inner one. Frequently both inner and outer zones show a patchy type of extinction, such as would result from submicroscopic microcline twinning. Occasionally cross-hatching is apparent in small areas, whilst in other crystals albite lamellae only are distinguishable. In either case the twinning is too fine to determine the extinction angle between the twin laths. One crystal resting on (001) distinctly shows three zones with extinction angles as given in Fig. 7. Microcline twinning appears in the centre zone.

When the crystals rest on (010) they usually extinguish as a single individual, the extinction then being 5° to 7° from the edge (010) (001). More rarely, zoning of a similar type to that observed on (001) is present.

The optical orientation agrees with that of the rhomb-shaped felspars from the Benbradagh sandstone.

These crystals, like those already described, are related to the anorthoclase-microcline series. On (001) the extinction angle in the centre zone is high for anorthoclase and rather suggests a soda microcline, whilst the extinction in the outer zone suggests orthoclase or anorthoclase. As before, the optic angle is less than the prism angle (inferred from the fact that the fast ray vibrates across the prism face, making a low angle with the edge (110) (001), i.e. less than 61° as is found in anorthoclase in igneous rocks.

3. Comparison with other Occurrences.

Authigenic felspar, both albite and orthoclase, has long been known to occur in non-metamorphosed limestones and dolomites on the Continent, and characterizes various horizons of Carboniferous, Triassic, Jurassic, Cretaceous, and Eocene age. In addition, orthoclase, which Daly [1] believes to be authigenic, occurs in the Waterton formation, Alberta, and Spencer [2] has shown albite crystals, found in limestone from Bengal, to be authigenic. A summary of the literature on the subject is given by Spencer [2] and Daly [3] and need not be repeated here. So far as the writer is aware, this is the first record of such felspars from arenaceous and argillaceous rocks.

Of the forms recorded in the present paper, the rhomb-like forms from the Triassic sandstone, Keuper Marl and Dolomitic Conglomerate resemble those described by de Lapparent [4] from the Muschelkalk of Alsace and Lorraine. The lath-like Carlsbad twins, however, do not appear to have been seen elsewhere. Grandjean [5] noted the presence of Carlsbad and Baveno twins in the Carboniferous limestone from Miatschkows, near Moscow, and Carlsbad twins in the Calcaire rose of Hallstadt, but the Carlsbad twins in both cases exhibit the usual form of two individuals flattened parallel to (010) and showing slight penetration.

The forms from the Magnesian Limestone can be matched by those recorded by Grandjean from various French limestones.

In optical characters, the presence of fine microcline twinning and zoning, the authigenic felspars here described, and more particularly those from the Magnesian Limestone, resemble those studied by Grandjean from the Chalk of the Paris basin,[6] and various horizons of Cretaceous and Jurassic limestones in France.[1],[2] These were referred to the microcline-anorthoclase series, and regarded as resembling microcline rather than anorthoclase, both optically and chemically, although it was noted that the optic axial angle is that of anorthoclase, being 44°.

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[1] R. A. Daly, "Low-temperature Formation of Alkaline Felspars in Limestones," *Proc. Nat. Acad. Sci.*, iii, pp. 659–65, 1917.

[2] E. Spencer, "Albite and other Authigenic Minerals in Limestone from Bengal," *Min. Mag.*, vol. xx, pp. 365–80, 1925.

[3] R. A. Daly, op. cit.

[4] J. de Lapparent, "Cristaux de feldspath et de quartz dans les calcaires du Trias moyen d'Alsace et de Lorraine," *C.R. Acad. Sci., Paris*, clxxi, pp. 862–5, 1920.

[5] F. Grandjean, "Deuxième note sur le feldspath néogène des terrains sedimentaires non metamorphiques," *Bull. Soc. Franc. Min.*, 1910, vol. xxxiii, pp. 92–7.

[6] F. Grandjean, "Propriétés optiques et génèse du felspath néogène des sédiments du Bassin du Paris," *C.R. Acad. Sci. Paris*, cxlviii, pp. 723–5, 1909.

4. ORIGIN.

Although a few writers have advocated a hydrothermal origin for authigenic felspar in limestone, or believed it to be formed in connection with local dislocation of the beds in which it occurs, the majority are agreed that it grew in the calcareous mud on the sea floor, the growth taking place during the deposition of the limestone. Grandjean believes that the crystals ceased to grow after they were buried, and considers it probable that similar felspars are crystallizing to-day on the sea bottom. De Lapparent [3] suggests that certain algae of the *Girvanella* group have been the primary cause in the production of albite crystals in the Flysch limestone of the Pyrenees, the action of these algae having been partly responsible for the formation of the limestone. He repeats this suggestion in connection with the orthoclase and microcline crystals from the Muschelkalk of Alsace and Lorraine,[4] and in the case of the Flysch limestone concludes that the felspars were formed at the time the rock crystallized. Lory [5] discovered secondary orthoclase crystals actually inside an ammonite shell.

The Benbradagh sandstone is calcareous, friable, and very much iron-stained. The detrital grains are angular and show no evidence of wind action and the material was probably accumulated by the action of small streams and deposited in water. After special treatment, a thin section of the rock was produced, in which the groundmass was retained, and the authigenic crystals can be seen in places round the thinned edge of the section.

The sandstone was pounded, boiled in HCl and after a prolonged search several kaolinized grains were found, from which crystals of authigenic felspar projected in a manner recalling the growth of anatase crystals from leucoxene. On one grain as many as six rhomb-shaped felspars appear. This strongly suggests that the felspar has grown from kaolin, directly or indirectly, by addition of potash.

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[1] F. Grandjean, "Le felspath neogene des terrains sedimentaires non-metamorphiques," *Bull. Soc. franc. Min.*, xxxii, pp. 103–33, 1909.

[2] F. Grandjean, "Deuxieme note sur les felspaths néogène des terrains sedimentaires non-metamorphiques," *Bull. Soc. franc. Min.*, xxxiii, pp. 92–7, 1910.

[3] J. de Lapparent, "Sur les cristaux du feldspaths developpés dans les calcaires du Crétacé supérieur pyrénéen," *Compt. Rend. Acad. Sci. Paris*, 1918, vol. clxvii, pp. 784–6.

[4] J. de Lapparent, "Cristaux de feldspath et de quartz dans les calcaires du Trias moyen d'Alsace et de Lorraine," *Compt. Rend. Acad. Sci. Paris*, 1920, vol. clxxi, pp. 862–5.

[5] C. Lory, "Sur la présence de cristaux microscopiques de minéraux du groupe des feldspaths, dans certains calcaires jurassiques des Alpes," *Compt. Rend. Acad. Sci. Paris*, 1886, vol. ciii, pp. 309–11.

It is well known that clays (hydrous aluminium silicates) exert a selective absorption on salt solutions, the alkali being absorbed whilst the acid is set free or combines with other bases. Potash is absorbed more readily than lime, magnesia or soda, and colloids are probably the most active absorbents. This absorption, which is sometimes of a chemical nature, might give rise to new minerals, e.g. Clarke[1] regards the absorption of potash and silica by colloidal ferric hydroxide as the final reaction in the formation of glauconite, the process being equivalent to that in which potassium compounds are taken up by clays.

Harris,[2] in investigating absorption phenomena, shown by soils and kaolin, found that kaolin in its natural condition does not affect a salt solution. If, however, it is first treated with an acid, and then washed, it has the power of liberating an acid from a salt solution. He suggested that the effect of the acid was to transform, by chemical reaction, some of the silicates into compounds which have the power of selective absorption.

This power to absorb potash and other alkalies possessed by aluminium silicates, in conjunction with the fact that felspar appears to have grown from kaolin in the Benbradagh sandstone, is suggestive as to the origin of authigenic potash felspar. All authigenic felspars so far recorded occur in calcareous rocks, i.e. in limestone, dolomite, chalk, marl, and calcareous sandstone, so that possibly calcium carbonate is concerned in their formation. Warington[3] found that hydroxides of iron and aluminium are most active as absorbents in the presence of calcium carbonate, which converts other alkaline salts into more easily absorbed carbonates.

Kaolin, or its amorphous equivalent, is probably present in small amounts in many limestones, it is certainly present in marl and to a small extent in sandstone. Acids, possibly from decaying organisms, may in some manner convert it to a state in which it has the power of selective absorption. Then, in the presence of calcium carbonate, potash is absorbed, either from the sea at the time of deposition of the ground rock, or at a later date from percolating water. How long the crystals take to grow it is impossible to say, but in the case of the sandstone it is unlikely that they can have formed before being covered, and possibly in all cases growth would continue during the consolidation of the rock. It does not seem impossible that such felspars might sometimes be of recent origin, having

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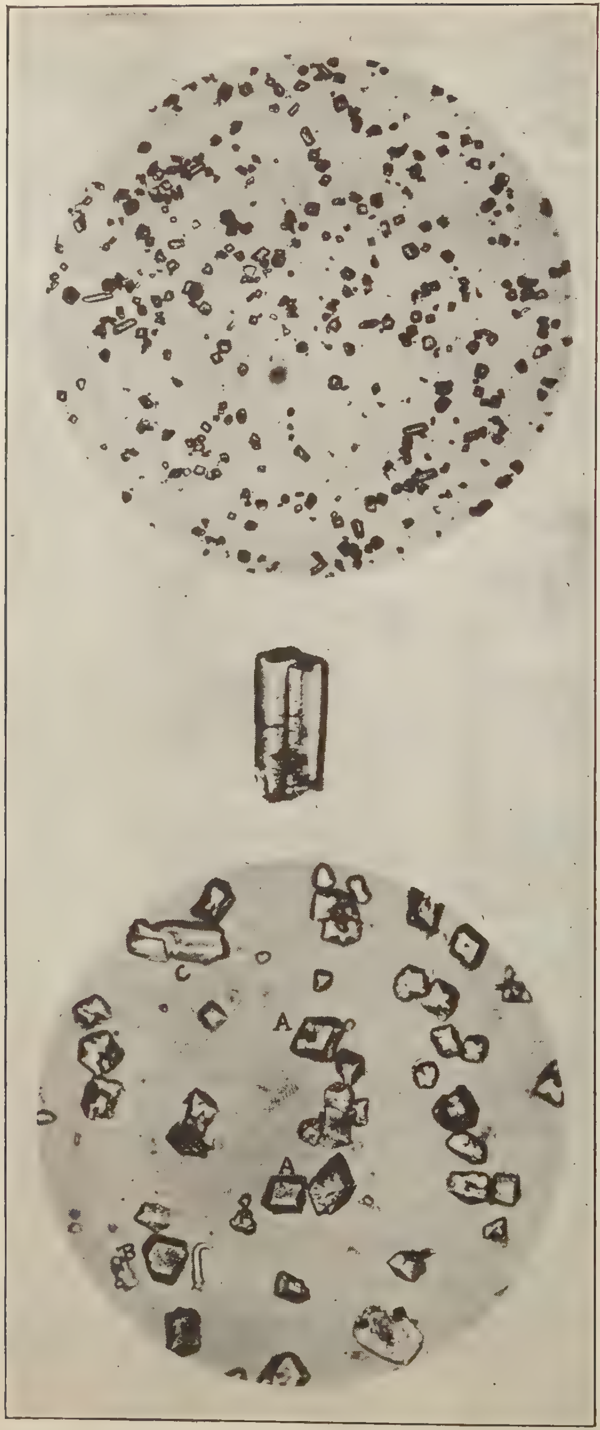
[1] F. W. Clarke, *Bull.* 695 *U.S. Geol. Surv.*, 1920, p. 514.

[2] J. E. Harris, "Some Absorption Phenomena in Soils and Kaolin," *Journ. Physical Chem.*, vol. xviii, 1914, p. 355.

[3] R. Warington, "On the Part taken by Oxide of Iron and Alumina in the Absorptive Action of Soils," *Journ. Chem. Soc.*, vol. xxi, 1868, p. 1.



AUTHIGENIC POTASH FELSPAR FROM THE TRIASSIC SANDSTONE AT BENBRADAGH HILL, CO. LONDONDERRY been formed by absorption from the ground water long after the rock has consolidated.

The writer wishes to thank Dr. Hawkes for the interest he has taken in the work, and for the suggestions he has made from time to time.

EXPLANATION OF PLATE XII.

Microphotographs of authigenic felspar from the Triassic sandstone at Benbradagh Hill, Co. Londonderry, mounted in water.

1.—Rhomb-shaped crystals and lath-like Carlsbad twins. × 67.

2.—A Carlsbad twin in which each individual shows the form $\{110\}$ $\{001\}$, and is elongated parallel to *c*. × 300.

3.—Crystals. × 200.

A. Showing development of $\{110\}$ $\{001\}$ and tabular parallel to (001).

B. Similar to A, but with $\{010\}$ developed.

C. Carlsbad twin, elongated parallel to *c*.

Further Studies in Chert. I.

By H. C. SARGENT, F.G.S.

(PLATES XIII AND XIV.)

INTRODUCTION.

DR. F. W. CLARKE truly observes in regard to the origin of chert: "No one process can account for all the occurrences of amorphous and cryptocrystalline silica, and each locality must be studied in the light of its own evidence." (*Data of Geochemistry*, 1916, p. 544.)

In these studies it is proposed to discuss the chief occurrences of chert in the British Isles in order to throw light, if possible, by both field and microscopic evidence on the processes that have led to their formation. Two important areas have already been treated in some detail, viz. the Lower Carboniferous Cherts of Derbyshire (1)[1] and the massive Chert Beds of North Flintshire (12).

The present paper will deal with the cherts in the Yoredale Series of the North Riding of Yorkshire, and also with certain minor occurrences believed to be of magmatic origin. For convenience the points at issue in the discussion on the origin of chert may be briefly re-stated. They are:—

(1) The relative age of the chert, whether contemporaneous with, or subsequent to the associated rocks.

(2) The origin of the silica, whether organic or inorganic.

(3) Whether the chert is of primary or metasomatic origin.

Evidence has been already given (1) to show that the Lower Carboniferous Cherts of Derbyshire were (*a*) contemporaneous with the associated rocks; (*b*) essentially of inorganic origin; (*c*) not of metasomatic origin. It is believed that the evidence then cited is of wide application to chert-formations, and it is needless to repeat it here. A few additional observations may, however, be made with advantage.

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[1] Figures in parentheses refer to references at end of paper.

THE RELATIVE AGE OF THE CHERT.

The term "tabular" is used by some geologists to denote all bedded cherts. Professor Reynolds, with special reference to the bedded cherts in D_2 of the Midlands and North Wales, and the Bishopston beds of Gower, describes them as "lenticular or nodular cherts developed along the bedding planes" (2, p. 97), with the clear implication that they are of subsequent formation.

I venture to think that field-evidence shows abundantly and unmistakably that this view cannot be sustained. Apart from the extensive, massive occurrences, such as those of North Flintshire, North Yorkshire, the Trough of Bowland and elsewhere, to which it is impossible to apply the above description, there are in every formation I have examined, including those to which Reynolds refers, extensive, often quite thin, stratiform beds which it seems clear were contemporaneous, stratified deposits. Such beds are far too extensive and well-bedded to admit of their being merely subsequent intercalations along bedding-planes. Professor Sollas, discussing similar beds of flint, suggests that they were possibly the result of gentle current action (3, p. 154). Such action would, of course, involve contemporaneity.

THE ORIGIN OF THE SILICA.

Contemporaneity seems clearly to rule out the theory of organic origin. The solution of siliceous organisms on the sea-floor, if it took place at all, would be too slow to allow of the formation of even the thinnest contemporaneous deposits (4, p. 231).

Not infrequently thick beds consisting of an intimate admixture of silica and calcium carbonate are met with. This feature will be discussed in the section on the Yoredale Cherts. It has also been extensively noted in South Wales. Dixon has termed these beds "incipient cherts" (5, p. 137). They seem to be clearly contemporaneous deposits of a hybrid nature. To quote F. W. Clarke again (op. cit., p. 545), "Silica and calcium carbonate may be deposited together in the same mud or ooze, forming a nearly homogeneous mixture."

Tarr states that there are no sponge spicules in American cherts (6, p. 9). Reynolds agrees that "it does not seem probable that they can have supplied the immense quantities of silica that are so often met with" (2, p. 100).

The supporters of the sponge-spicule theory seem always to overlook the fact that there must have been an abundant supply of silica already in solution where the sponges lived and grew, otherwise they would not have been there! The explanation of their occurrence in thin sections seems clearly to be that when, through increasing saturation or other causes, precipitation took place some were inevitably embedded in the gel.

It is not proposed in this paper to discuss again the chemical processes leading to coagulation and precipitation. The hitherto somewhat conflicting results of published experimental work suggest the wisdom of postponing further speculation. For the present purpose the well-known facts that silica in solution is contributed by some rivers to the sea in enormous quantities, and that under favourable conditions it may be precipitated as a gel, are sufficient.

THE PROBLEM OF REPLACEMENT.

There is little to add to the evidence against a general metasomatism of the country-rock given in the discussion of the Derbyshire Cherts (1, p. 270). That evidence will, it is believed, apply substantially to all occurrences of chert in limestone, with the exception of the vein-cherts discussed below. Presumably the advocates of metasomatism will not claim it in respect of the numerous cherts in non-calcareous rocks—shales, sandstones, or igneous rocks.

Unquestionably a limited and local silicification of limestone and calcareous organisms has often taken place, the metasome being always, as pointed out in the above-cited paper, clear crystalline silica (Plate XIII, Fig. 5). Tarr has recently emphasized this view (6, p. 11). The occurrence of minute grains of calcite, not infrequently seen under the microscope within a clear, crystalline matrix of silica, suggests local silicification of inclusions of limestone. It seems clear, however, that the impure, often highly pigmented silica, of which many cherts consist, cannot have taken part in any replacement reaction.

Hallimond points out (9, p. 90) that " the presence of unaltered calcite shells in a sideritic groundmass is conclusive evidence against the theory that the Cleveland ore originated in the general replacement of a limestone ". The same argument seems to apply to the case of chert.

In South Pembrokeshire, where there are unique opportunities for the study of different forms of chert, I have noted at various localities isolated nodules weathered out on a base of unaltered calcareous fossils. An analogous occurrence may sometimes be seen in the Carboniferous Limestone of Derbyshire (e.g. in the Station Quarry at Matlock Bath), where nodules have formed within the concave surfaces and between the valves of unaltered shells of *Productus*. The explanation is doubtless that decaying organic matter has attracted and precipitated silica in dilute solution in the sea-water, but there has been no replacement of the calcareous shells.

DEVELOPMENT OF THE GEL.

Very frequently in geological literature, and even in text-books, the cryptocrystalline silica of which chert largely consists is incorrectly termed " chalcedony ". Chalcedony, whether it be an independent mineral or a form of quartz (a point on which opinions differ) is not uncommon in cherts, where it is a late stage in the dehydration and crystallization of the gel.

Opal is rarely seen in cherts. Isotropic silica is not uncommon, but it is rarely opal. It contains less water and has consequently a higher refractive index than opal. It is also harder and has a higher specific gravity than that mineral (7, p. 428).

Incipient crystallization appears to start at an early stage in the development of the amorphous gel. It doubtless ensues on partial dehydration and consequent increase of saturation. Powdered fragments of cryptocrystalline chert are seen under the microscope to contain minute, isolated, feebly birefringent spots (centres of crystallization) in a base of isotropic silica. In more advanced stages, where development has not been arrested (possibly through the inhibition of further dehydration by the presence of impurities), the centres of crystallization are larger and more numerous, and may tend to coalesce (microcrystalline structure). It is noteworthy that the isotropic and cryptocrystalline cherts give much more water in the closed tube than those in which the structure is microcrystalline.

The last stages of crystallization, not always reached, where dehydration is still more advanced, are seen in the development of small tracts of chalcedony and quartz-mosaics. The quartz has often undulose extinction.

Scott has pointed out that there is probably, so far as water-content is concerned, a continuous series from opal to chalcedony and quartz, and that " the geological evidence is very strongly in favour of the continuity of the above series and the absence of definite hydrates " of silica (8, pp. 221, 222). It is worthy of note that all the forms of silica seen in cherts, other than definite quartz, and not excluding chalcedony as will be shown below, have varying refractive indices (Becke test) indicating varying water-content.

Silica-gels, too, are probably not derived from silicic acids of definite composition, but may contain varying amounts of adsorbed or dissolved water (6, p. 25, with references). It seems probable that varying viscosity would follow varying water-content, and it is possible that we have here an explanation of the difference in form between the concretionary nodules and the bedded cherts, the former resulting from more viscous material than the beds spread out on the sea-floor. There seems to be no reason to assume essentially different origins for these two forms of chert.

Definite evidence of derivation from a gel is shown by gradations of crystallization, and also by colloform and gel-structures which will be discussed and illustrated below.

The pigmentation of the gel by impurities, showing as impurities in the chert, may be effected by various agencies. Among these, organic colloids appear to play an important part. Such colloids, as shown by Bassett (15, p. 14) may be either positively or negatively charged, and they may therefore be adsorbed by other colloids having a similar charge. This seems to explain the black or dark colour of many cherts due to carbonaceous impurity. The negatively charged colloidal silica has adsorbed similarly charged organic colloids.

Cox, Dean, and Gottschalk have shown by experiment (11, p. 65) that sulphides of the metals, because of the ease with which they form colloidal solutions and are adsorbed by colloidal silica, may also produce a black or grey colour in cherts.

It has been shown (12, p. 177) that a blue colour may result from the presence of ferrous iron, which readily oxidizes to a rusty brown colour.

In the white cherts the silica is very free from impurity and the crystallization is often well advanced.

Internal reflection of light also affects the colour in close-grained cherts free from impurity, producing a black translucent rock.

THE YOREDALE CHERT SERIES.

These cherts have been studied in Arkengarthdale and Swaledale, in the North Riding of Yorkshire, where they are finely developed.

Hudson has shown that the Yoredale rocks of Wensleydale consist of a series of rhythmic successions, repeated several times, of (in ascending order) shales, sandstone, limestone (10, p. 125). This feature holds good also in Arkengarthdale and Swaledale. Chert is generally developed at or near the top of the highest limestones. They are known as :—

(3) The Crow Series, containing the Crow Cherts.
(2) The Main Limestone, passing up into the Main Chert.
(1) The Undersett Limestone, passing up into the Undersett Chert.

Between the Main and the Crow beds there is in places a bed known as the Little Limestone, which often contains a cherty development, but it is of no importance in the area here considered.

Apart from a somewhat rare occurrence of nodules, these cherts have invariably been laid down in evenly stratified beds, varying in thickness from an inch or two up to 3 or 4 feet. They are clearly conformable, contemporaneous deposits, and the term " tabular " with its usual implication is quite inapplicable here.

A feature common to all the series, wherein they differ from many cherts in Carboniferous Limestone, is the frequently transitional character of the passage upwards from the underlying limestone. These passage-beds appear generally to consist of an intimate admixture of limestone and silica in varying proportions, forming a hard, tough rock. In some localities this hybrid character persists through the entire thickness of the outcrop, and even in the purest beds there are often short bands and patches of limestone with a transitional passage into the chert. In the whole area there are only three localities, noted below, where true chert occurs in sufficient quantity to be worth working.

The Undersett Chert.—Tracing the beds south-eastwards down Arkengarthdale towards Reeth, in Swaledale, a distance of about 6 miles, this chert is exposed in Great Punchard Gill, where the outcrop is about 20 feet thick ; in Hungary Quarry (25 feet) ; in the Low Level Mine ; in the faulted vein west of Langthwaite ; on Calver Hill ; and on Fremington Edge, near Reeth. Between Calver Hill and Fremington Edge the chert appears to die out, but it thickens again to about 20 feet at the south-east end of the Edge, where it attains its greatest purity and is extensively mined, by levels driven into the hillside, for export to the Potteries. The chert is also worked in the Low Level Mine for the same purpose.

Large chert-nodules occur within the massive Undersett Limestone on Fremington Edge above the bedded chert.

The Main Chert.—This chert is well exposed on the north bank of the beck in Great Punchard Gill, where it is about 20 feet thick and hybrid throughout ; in Hungary Quarry, where the beds are much disturbed but the thickness is probably at least 40 feet ; and in the faulted vein west of Langthwaite. On Calver Hill the Main Limestone is without chert. On Fremington Edge I have noted none on the top, but in an old quarry above Castle Farm it occurs, exceptionally, at the base of the Main Limestone in thin beds up to 4 or 5 inches thick, associated with a bluish, siliceous limestone known to the miners as " silex ".

The Hungary Quarry is the only place in the district where the Main Chert is worked, about 4 or 5 feet of the upper part, a blue rock, being of sufficient purity for commercial purposes. Barytes associated with fluorite occurs in joints and thin veins in the upper part of the quarry. The chert here has an eroded upper surface with numerous shallow, usually circular pits, up to 4 or 5 inches in diameter. Their origin requires explanation. This erosion supports Hudson's view that the limestone facies closes the rhythmic succession.

The Crow Chert.—The Crow Series is well seen in Great Punchard Gill. Here it is some 65 feet thick and consists of alternating limestones and shales, containing well-bedded bands of chert a few inches thick, at various levels. A bed about 3 feet thick occurs midway in the series. The limestones are usually a siliceous, hybrid rock.

The Crow Chert is also seen to a thickness of 10 feet at about 1,500 feet O.D. on the summit of Fremington Edge, resting on Crow Limestone of which about 25 feet are exposed. It is also seen on Whitaside Moor, about 4 miles south-west of Reeth, where, at about

1,750 feet O.D., it crops out in a small beck, tributary to the Swale, and forms a small waterfall. It is here about 6 feet thick. The Crow Cherts often contain a very mixed assemblage of fossils, mainly calcareous (Plate XIII, Fig. 5), and are rarely free from a considerable admixture of calcium carbonate.

It will be noted from the foregoing that the Yoredale chert-beds tend to be discontinuous. It seems probable that they were deposited in shallow basins in the limestones. Of all the localities mentioned above, it is only in Great Punchard Gill and on Fremington Edge that the entire series can be seen in succession. Throughout the area here considered the beds have gentle dips, or sometimes none at all, and are very free from disturbance except where faulted.

PETROLOGY OF THE YOREDALE CHERTS.

Megascopic Characters.—The colour varies from white to dark grey, brown, black, and blue. The blue is a very pure chert and has the highest value for commercial purposes. In the Hungary Quarry the uppermost 4 or 5 feet of the Main Chert are blue, with 6 or 8 inches at the top, underlying shales, oxidized to a rusty brown. Blue chert also occurs, and is worked in the upper part of the Undersett beds on Fremington Edge and in the Low Level Mine.

Not infrequently, especially in the Undersett Cherts, the individual beds have a core of translucent, black chert within upper and lower layers of a hybrid chert, containing a considerable amount of calcium carbonate. A similar feature has been noted in the North Flintshire Cherts (12, p. 174). It is believed to result from segregation of the silica in an originally calcareous chert. It is, however, difficult to see why segregation should take place in some cases and not in others, as for instance in the cherts which are hybrid throughout, as noted above.

The hardness of the Yoredale Cherts varies considerably. Where there is much calcareous admixture the rock is often scratched by the knife-blade. The true cherts have the hardness of quartz.

Small inclusions of a white quartz-mosaic in streaks and patches a few inches in length, are often seen. Irregular vein-like streaks and bands of white chalcedony are common in the Undersett Chert on Fremington Edge. These features appear to be infillings of open spaces resulting from shrinkage of the gel on dehydration. Cox, Dean, and Gottschalk (11, p. 53) state that these shrinkage cavities are the most common evidence of derivation from a gel. It is noteworthy that they appear to be restricted to the purer cherts in which dehydration is most advanced.

A coarse horizontal banding in light and dark layers, possibly due to segregation of impurities by crystallization, is not uncommon.

Microscopic Characters.—The silica of these cherts shows all gradations of development from the amorphous state through cryptocrystalline material to chalcedony and quartz-mosaics.

It is noteworthy that in the hybrid rocks, described above, the silica is usually very impure and uniformly isotropic or feebly cryptocrystalline, without gradations of crystallization. This material gives much more water in the closed tube than the cherts in which the crystallization is more advanced. It is obvious that, for some obscure reason, dehydration has been largely inhibited, with consequent arrest of crystallization. The same feature has been noted in calcareous cherts from other districts.

It seems clear that this impure, undeveloped silica cannot be of metasomatic origin, otherwise it would have developed into clear, crystalline material. That a local and incomplete silicification has probably sometimes occurred is shown by the presence of minute grains of quartz within patches of limestone in the hybrid rocks. Again, minute grains of calcite, probably relics of the replacement of limestone inclusions, are sometimes seen in a matrix of clear crystalline silica.

In the purer cherts quartz-mosaics and chalcedony are often developed in small tracts within the matrix. The quartz has usually undulose extinction. Rarely, euhedral crystals are seen. These minerals also occur in cavities, doubtless due as suggested by Tarr (6, p. 15) and as in the megascopic occurrences described above, to shrinkage of the gel on dehydration (Plate XIII, Fig. 1). In these features there is often a core of quartz surrounded by chalcedony.

It is important to note that these shrinkage cavities are rarely, if ever, seen in the impure cherts noted above, in which dehydration has been largely inhibited. The cavities often take the form of branching, vein-like cracks, varying greatly in width. They are usually filled with silica, which sometimes remains cryptocrystalline but is more often developed into chalcedony or quartz (Plate XIII, Fig. 4). There is sometimes a slightly transitional passage into the matrix, or the edges of the cracks may be serrated by the fibres of chalcedony or the grains of quartz penetrating the matrix (Plate XIII, Fig. 3). These features support the view that the cracks and their infilling were contemporaneous and not due to disturbance subsequent to consolidation.

Calcite fills some of the cracks and a slight replacement by crystalline silica at the contact with the matrix suggests contemporaneous deposition of carbonate of lime from the surrounding rock.

Other calcite veins, usually very thin, appear to be of later date. They cut across the chalcedony in the fissures and cracks, breaking at the contact with the quartz, or winding their way between the grains (Plate XIII, Figs. 1 and 4). The origin of these later veins is obscure. They may possibly indicate a late shrinkage phase.

The chalcedony in these shrinkage features affords an interesting study. When viewed by transmitted light it is often white, but not infrequently brown, sometimes in well-defined bands of varying shades of colour. Both brown and white often occur side by side in parallel bands (Plate XIII, Figs 1 and 2). By reflected light the true colour of the brown material is seen to be white. It is noteworthy that the refractive index *decreases* with each *increase* of colour. It is highest in the white band and becomes lower with each successive shade of brown (Becke test).

The brown colour is, of course, an optical effect, and Pirsson has shown that it may be due to internal reflection of some of the rays of light owing to the fibres acting as prisms.

The fibres are always optically continuous through all the shades of colour, and their birefringence decreases with depth of colour. If the prism-action of the fibres were the sole cause of the optical effect in transmitted light, it is difficult to see why the entire length of the fibres, including the white portion, should not be equally affected.

The varying refractive indices of the bands indicate differential dehydration, the water-content increasing with decrease of index, and it is believed that increasing water-content produces increased internal reflection with the consequent variations of opacity and birefringence.

There is sometimes a transitional passage between the different shades of colour. The variations of refractive index are then masked but the varying birefringence remains.

It seems highly probable, therefore, that chalcedony may have a varying water-content, and that, like other hydrated forms of silica, it is not a mineral with a definite composition.

The gradations in crystallization, and the pronounced gel-structures noted in the foregoing description, show clearly that the Yoredale Cherts were derived from silica-gels, varying in purity from place to place.

Rhombohedral crystals of a carbonate assumed to be dolomite, which have clearly crystallized in situ, are not uncommon in these, as in many other cherts (Plate XIV, Fig. 3). Their presence is further evidence against a general metasomatism. Both silicification and crystallization of carbonates could hardly proceed simultaneously in the same medium!

In one or two slides there are irregular, opaque and semi-opaque bodies which are difficult to determine. Dr. H. H. Thomas, who has kindly examined one of the slides, points out that some of them have a rhomboidal form and look like pseudomorphs of iron oxide after a ferrous carbonate or a ferriferous dolomite.

Detrital material is much scarcer in these than in many cherts. A few minute grains of quartz, up to ·09 mm. in diameter, and a few flakes of white mica have been noted in two or three slides. It seems clear that mechanical erosion was in abeyance whilst the adjacent land-surface was undergoing chemical degradation.

The occurrence of veins of barytes and fluorite in the Main Chert in Hungary Quarry has already been mentioned. The same minerals occur in microscopic quantity in the Undersett Chert on Fremington Edge.

Organic Remains.—Many thin sections show abundant organic remains, both siliceous and calcareous. Many others contain none at all. The only siliceous organisms are sponge-spicules, in cross sections and broken rods, with which some thin sections are crowded. No radiolaria have been noted. The calcareous organisms are very fragmentary and are mostly unaltered. Some are partially, some wholly silicified. The silicification has been selective and local and the alteration is to pure, crystalline silica, usually microgranular quartz.

Typical fossiliferous thin sections have been submitted to Dr. Stanley Smith, and he has kindly reported on them as follows :—

> " Slide 741*a*. Crow Chert (Whitaside Moor, Swaledale). The section, which has a markedly streaky appearance, is crowded with sponge-spicules. The silica spicules probably belong to the genus *Hyalostelia* (Zittel). The circular and rod-like sections of calcite are in my opinion spicules of one of the Calcispongia, possibly allied to the genus *Peronella* (Zittel). One or two of these clearly show a central canal. Besides these there are some other organic fragments which have resisted silicification, including some ostracod valves." (Plate XIII, Fig. 6.)
>
> " Slide 742, Crow Chert (Whitaside Moor, Swaledale). In this section organic fragments are abundant and represent several phyla. Most, however, are those of crinoids, crinoidal ossicles and plates, the structure of which is beautifully picked out by iron staining. The remaining organisms include sponge spicules, Foraminifera (*Trochammina* ?) and shell fragments."
>
> " Slide 884, Main Chert (Hungary Quarry, Arkengarthdale) and Slide 887, Undersett Chert (Fremington Edge). Sponge spicules are plentiful in these sections, but beyond these there is little else."
>
> " Slide 937, Calcareous Chert, Crow Beds (Great Punchard Gill, Arkengarthdale). This section, like 742, is crowded with organic particles. These, however, cover a still wider range of marine life. Whilst, as in the case of the slide quoted, crinoid ossicles predominate, there are shell fragments among which those of Brachiopods can be recognized, Bryozoa, tests of Ostracods, echinoid spines, sponge spicules, and a Foraminifer—undoubtedly *Stracheia* ; all of which are plentiful.
>
> " Slide 1048, Main Chert (Fremington Edge, near Reeth). The organic contents of this slide are mostly sponge spicules, but there are several large shell fragments (Brachiopoda)."

Dr. Stanley Smith adds to the foregoing report : " Having examined your sections I would suggest that the sponges contribute little to the silica of the chert, but are merely present along with other marine organisms of the time and place."

The mixed assemblage and fragmentary character of these organic remains suggest that they are merely incidental fossils washed into and embedded in the gel.

Conclusions.—The following conclusions are drawn from this study of the Yoredale cherts of North Yorkshire :—

(1) The chert-beds were original, contemporaneous deposits and are believed to have been laid down in a shallow sea bordered by a peneplaned land-surface.

(2) The silica was essentially of inorganic origin resulting from chemical decomposition of a land-surface, and was precipitated on the sea-floor as a gel. Siliceous organisms (sponges) throve where there was an abundant supply of silica in solution, and when precipitation occurred some were inevitably embedded in the gel. Calcareous organisms often suffered the same fate.

(3) Microscopic evidence shows that a selective silicification of limestone and calcareous organisms within the chert has taken place locally, but there has been no general metasomatism of the country-rock.

CHERTS OF MAGMATIC ORIGIN.

The wide-spread association of some cherts with submarine volcanic rocks, from which it is believed that their silica was derived, is well known. A valuable paper by Sampson (16), to which Dr. R. L. Sherlock has kindly called my attention, shows that the ferruginous cherts of Notre Dame Bay (Newfoundland) are associated with pillow-lavas and tuffs, to which he ascribes their origin. His paper contains abundant references to the literature of the subject which need not be repeated here, and he suggests possible chemical processes involved in precipitation.

The ferruginous character often present in cherts of this class (jaspers associated with pillow-lavas may be cited as an illustration) is noteworthy. Sampson suggests (16, p. 597) that it seems reasonable that magmatic waters from volcanic rocks would carry considerable ferrous iron, which, when the solution was mixed with ocean water, would be oxidized and by hydrolysis converted into ferric hydroxide. This colloidal ferric hydroxide, which carries a positive charge, might then neutralize the negative charges of the associated colloidal silica, with consequent coagulation and precipitation of both (16, p. 598). This process may explain the iron oxide present in jaspers and other ferruginous cherts.

The occurrence in Derbyshire of a thick bed of chert in close association with a lava-flow, to which a magmatic origin is ascribed, has already been discussed (1, p. 275). A few minor occurrences in the same county and elsewhere will be briefly described.

At New Bridge, near Ashford (Derbyshire), a thin, ferruginous chert occurs in joints of the olivine-dolerite sill described by Bemrose (13, p. 274). The sill is overlain by a lava-flow. In thin section the chert is seen to consist of a rough network of segregated haematite, with microgranular quartz lining the meshes and microcrystalline silica, often iron-stained, filling the interspaces (Plate XIV, Fig. 4). In places the silica occurs in numerous, small lath-shaped bodies resembling pseudomorphs after felspar microlites or small laths, embedded in haematite.

Residual solutions escaping from the igneous rock have doubtless supplied the material composing this chert.

On Conway Mountain (North Wales) an occurrence in the Upper Brecciated Rhyolites, analogous to that at New Bridge, has been recorded by Dr. G. L. Elles as " a black chert-like substance " . . . " filling the joints and minutest interstices of the rock." (14, p. 177.) A thin section shows it to consist of a rough network and straggling patches of iron ore in a matrix of clear crystalline silica (Plate XIV, Figs. 5 and 6). Gel-structure in the silica is well shown by a banded structure. The bands run concentrically around patches of iron-ore, or in circles in the larger interspaces. They have higher refractive index, indicating greater dehydration, than the silica between the bands. Their width is about 0·019 mm. Between crossed nicols the bands are microcrystalline, the intervening silica being often almost inert, but tracts of quartz-mosaics are also developed covering both the bands and the intervening silica.

The rock is clearly a ferruginous chert and doubtless of magmatic origin.

In some of the lead-mines of Derbyshire there are veins of chert, within the Carboniferous Limestone, which probably owe their formation to ascending emanations from underlying magmatic sources, carrying silica together with fluorine and barium in solution. Finlayson points out (17, p. 310) that, in the formation of lead and zinc veins, the filling of open cavities, rather than replacement of country-rock, was the chief feature of deposition, but that in limestone districts silicification and dolomitization of the wall-rock have also taken place (op. cit., p. 307). These observations appear also to apply to the chert-veins here discussed, although in them metallic sulphides are subordinate and not always present. There is sometimes definite evidence of replacement of wall-rock ; in other cases the filling of fissures appears to have been the chief feature.

In the Jingler Mine at Wakebridge, on the western side of the Crich Inlier, a vein of white microcrystalline chert, 18 inches wide, contains idiomorphic fluorite, patches of dolomite, and small aggregates of lath-shaped crystals of barytes (Plate XIV, Fig. 1). Numerous very minute needles of a micaceous mineral are also present. They have an average length of 0·03 mm.

In the Mawstone Mine, near Youlgrave (Derbyshire), there is an incrustation of white crystalline chert, 2 inches thick, left on the wall-rock of the Wenley West vein after excavation of the vein by mining operations. Fluorite, barytes and a little galena are associated with the chert in the vein. In the Timperley vein, in the same mine, a vein of blackish crystalline chert fills a fissure in the limestone 2 feet wide. It is only seen for a few feet, and then thins out to a feather-edge in the limestone. In this case considerable replacement of limestone has probably taken place. Thin sections show minute grains of calcite and ragged fragments of limestone within the silica. One of the thin sections shows traces of organisms on which Dr. Stanley Smith reports as follows: "Slide 906. The organisms in this section are mere ghosts. Some sponge-spicules are recognizable, and I believe there are traces of encrinite fragments, ostracod valves and foraminifera."

These vein-cherts consist of clear crystalline silica ranging in development from microcrystalline material to fine development of chalcedony and quartz-mosaics. There are also in places smudges of dusty, white material, believed to be the remains of argillaceous impurity in the replaced limestone.

An interesting feature in the quartz-mosaics is the segregation of impurity, similar to the above, by crystallization (Plate XIV, Fig. 2). Thin sections show shrinkage cavities containing chalcedony and quartz, and the structure of the chalcedony is similar to that in the Yoredale rocks, described above.

No toadstone has been reached in the Mawstone Mine, but it is known to be present in neighbouring mines near Youlgrave and Alport, and there is an outcrop in Bradford Dale less than a mile away (13, p. 257). The lava of Crich Hill is probably responsible for the vein-chert in the Jingler Mine.

The various structures seen in these vein-cherts—the gradations of crystallization, the segregations of iron oxides bordered by clear crystalline silica, the shrinkage cavities, the concentric bands of silica—must have been formed when the silica was in a gelatinous condition. The occurrences described, though of no great individual importance, are of interest as showing the frequent formation of chert by magmatic processes.

ACKNOWLEDGMENTS.

I am indebted to many friends for much kind assistance. Reference has already been made to Dr. Stanley Smith's generous help. Dr. H. H. Thomas and Professor W. T. Gordon have assisted me petrologically. Professor Boswell and Dr. E. Neaverson have given helpful criticism, and I am indebted to Mr. Ernest Dixon for much discussion of the problems involved, without in the least implying that he agrees with my conclusions. Messrs. T. Ward and J. Wagstaff, of Reeth, have kindly given me the benefit of their intimate knowledge of the district. I have also to thank Mr. G. S. Sweeting for the great pains he has taken with the photo-micrographs.

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EXPLANATION OF PLATES XIII AND XIV.

PLATE XIII.

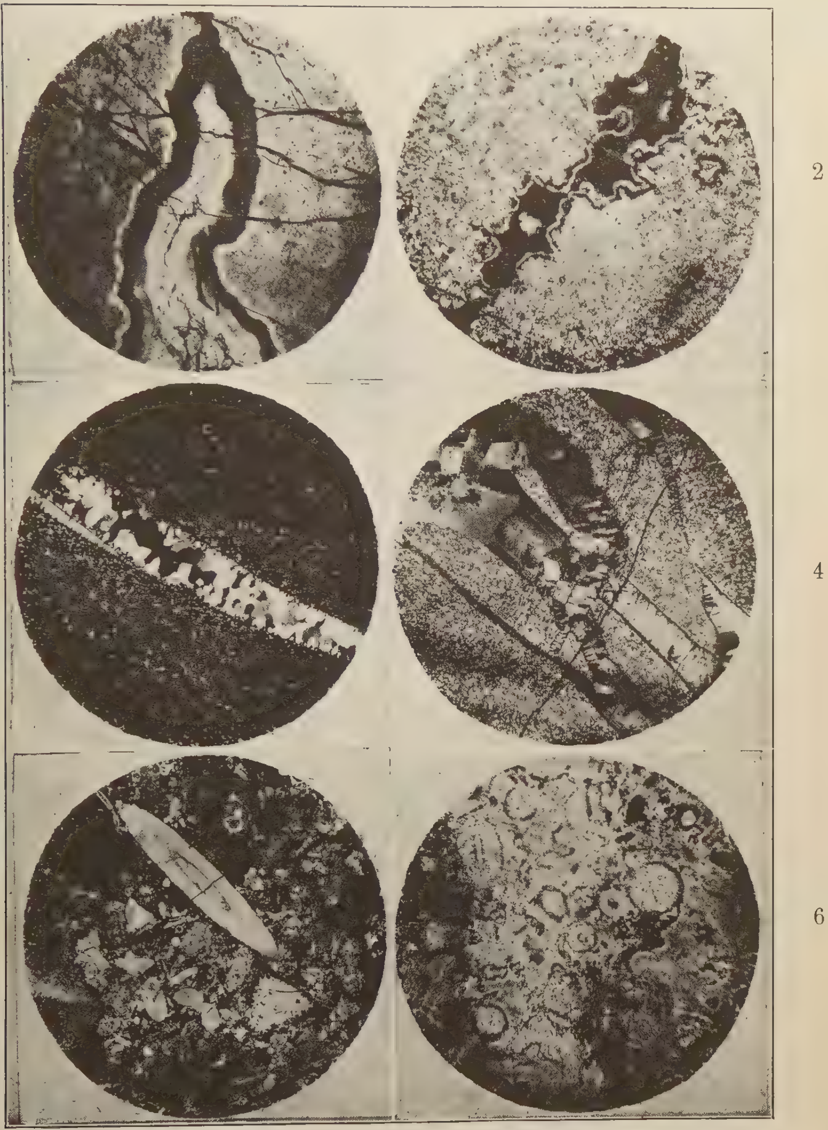
FIG. 1.—Undersett Chert, Fremington Edge, near Reeth. Ordinary light, × 18. (Slide 887.) A shrinkage cavity in microcrystalline chert is shown. The walls of the cavity are lined by chalcedony showing, by transmitted light, three shades of colour, an outer white band and two brown bands within. The white core of the cavity is a quartz-mosaic. Veinlets of calcite cut across the chalcedony, but are distorted at the contact with the quartz.

FIG. 2.—Undersett Chert, Fremington Edge. Nicols crossed, × 18. (Slide 735.) Another shrinkage-cavity in microcrystalline chert is seen. Here the band of white chalcedony lies within and parallel to the margin of the brown, which fills the bulk of the cavity. The birefringence of the brown chalcedony is very low.

FIG. 3.—Undersett Chert, Fremington Edge. Nicols crossed, × 18. (Slide 1043.) A shrinkage-crack in microcrystalline chert is shown. The infilling consists of a quartz-mosaic, with a thin fringe of chalcedony on either side of the quartz at the left-hand end. The grains of quartz and the fibres of chalcedony penetrate the matrix.

FIG. 4.—Undersett Chert. Fremington Edge. Nicols crossed, × 10. (Slide 1012.) Branching shrinkage-cracks filled by chalcedony in a matrix of microcrystalline chert. Veinlets of calcite cut across the chalcedony.

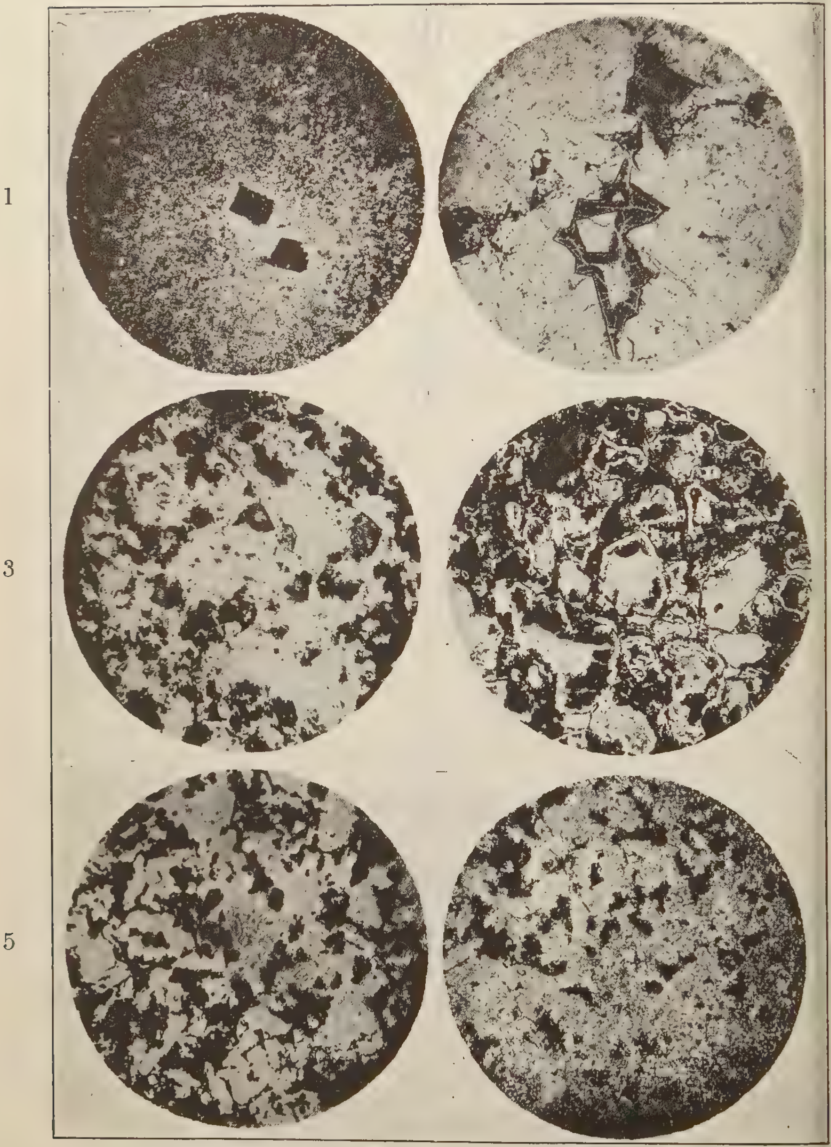
FIG. 5.—Calcareous Chert, Crow Series, Great Punchard Gill, Arkengarthdale. Ordinary light, × 15. (Slide 939.) Selective silicification of calcareous organism is seen. The large encrinite stem is entirely silicified. Other calcareous organic remains are partially or wholly replaced, others are unaltered.



Photomicro. *G. S. Sweeting.*

HOTOMICROGRAPHS OF CHERTS, YOREDALE SERIES, NORTH YORKSHIRE.

[*To face p.* 412.



Photomicro. *G. S. Sweeting.*

PHOTOMICROGRAPHS OF CHERTS, DERBYSHIRE AND NORTH WALES.

Fig. 6.—Crow Chert, Whitaside Moor, Swaledale. Ordinary light, × 90. (Slide 741*a*.) Calcispongia, unreplaced, in a matrix of microcrystalline silica.

PLATE XIV.

Fig. 1.—Vein-Chert, Jingler Mine, Wakebridge (Derbyshire). Nicols crossed, × 20. (Slide 933). Idiomorphic fluorite in a matrix of microcrystalline silica.

Fig. 2.—Vein-Chert, Mawstone Mine, Youlgrave (Derbyshire). Ordinary light, × 30. (Slide 872.) Segregation of impurities by crystallization in a quartz-mosaic. The outline of the bands of impurities shows an impulse to idiomorphism on the part of the crystallizing quartz.

Fig. 3.—Main Chert, Fremington Edge, near Reeth. Ordinary light, × 80. (Slide 1048.) Rhombohedra of dolomite in a matrix of microcrystalline silica.

Fig. 4.—Ferruginous Chert, New Bridge, near Ashford (Derbyshire). Ordinary light, × 20. (Slide 918.) Haematite (black) segregated into a rough net-work, with thin bands of quartz lining the meshes. The inner spaces consist sometimes of clear microcrystalline silica (white), sometimes of iron-stained silica (black).

Fig. 5.—Ferruginous Chert, Conway Mountain (North Wales). Ordinary light, × 20. (Slide 730.) Iron oxide (black) segregated into irregular streaks and patches in a ground of clear, crystalline silica showing gel-structure.

Fig. 6.—The same as Figure 5, between crossed nicols. Small areas of quartz-mosaics are seen in position of illumination (white).

Some Characteristic Structural Types in Eastern Asia and their Bearing upon the Problem of Continental Movements.

By J. S. Lee.

(PLATES XV–XVII.)

(*Continued from page* 375.)

We have perhaps gone a little further into the detail of these five zones than is justified by the nature of this paper. But as we shall see later, unless the supreme importance of these east and west zones be fully appreciated, we should be at a loss to explain the peculiar arrangement of the several mountain ranges that swell forward towards the continental margin, as well as the succession of island arcs that border the continental mass of Eastern Asia.

Of the five east and west zones described above, the second was the one last recognized by the writer in a roundabout way. As the experience in recognizing this particular zone has served as a confirmation of the equidistant distribution of the five zones and also has proved a valuable hint for tracing similar zones in other continental areas, it may be worthy of note. By comparing the latitudinal positions of the east and west zones of eastern Siberia, Inshan, Tsinling and Nanling, it was realized that the Siberian zone and that of the Inshan were separated by about 16 degrees, while the Inshan, Tsinling and Nanling only by an interval of about 8 degrees. The distance between the Siberian zone and the Inshan would then be exactly double of that between the rest of the successive zones. This curious fact led to a search along the northern border of Mongolia which is located just half-way between the Siberian zone and the Inshan. Attention was at once attracted by the remarkable structure of the Tannu and Kentei. Thus, on the geological standard of accuracy, the 8 degrees interval between the east and west zones may be considered as established in Eastern Asia.

Still more amazing is the fact that structures of a similar nature occur in Western Europe. There, we find the Variskian or Hercynian zone extending from the northern border of the Bohemian massif to the south-western corner of Ireland and covering the latitudes from 50° to 52° N. Its mean position is then approximately located in 51°. Renewed compression along this zone during the Alpine phase of movement is indicated by sharp folding, for instance, in the Isle of Wight. The next east and west zone to the south is the Pyrenees-Cantabrian Range located in between 42° 20′ and 43° 20′ or in 42° 50′ on the average. The Atlas Ranges as a whole cannot be readily incorporated in these zones; for they embody elements of different trends and therefore probably of different origin. In the Mediterranean Atlas we may say that the dominant structural axes generally run east and west, but to the south of the Plateau of the Shotts the several ranges, such as the Saharan Atlas, the Middle Atlas, the Great Atlas, and the Anti-Atlas, no longer trend east and west but rather W.S.W. or S.W. If an analysis be made on this basis, we might separate the Mediterranean Atlas from the rest of the Atlases, and attribute the former to the east and west zones. It is to be noted that the average position of the Mediterranean Atlas is approximately in the latitude of 35° N. At least this is true for its western portion. Now comparing the mean positions of these zones with one another and with the east and west zones of Eastern Asia, it will be found that there is an interval of about 8° of latitude between these zones, and that they correspond respectively to the Tannu-Kentei, Inshan and the Tsinling Ranges. On the whole, however, the Eastern Asiatic zones are further south by about one degree or more as compared with the Eurafrican zones. Herein we may find a clue for determining the absolute amount of the bodily movement of Eastern Asia since the completion of the five zones.

This rhythmic distribution of the east and west zones is by no means accidental, but must have a profound meaning hitherto undiscovered. From the fact that equivalent zones are developed in certain parts of the Southern Hemisphere, as will be referred to later, it appears that there is no mode of deformation that can more fittingly explain the genesis of these zones other than zonal harmonics of some high order. The problem is of a quantitative nature; its final issue must, therefore, be determined on a quantitative basis.

Reverting to our discussion on the direction of movement of thrust masses, we are now able to demonstrate, through the reality of facts, the illusive nature of the conception that the pressure originated from, or the actual movement was effected by, the overthrust side alone. We have already seen that in the Inshan Range the overthrusts are mainly directed to the north; whereas in the Tsinling Range they are essentially directed to the south. The North Sinian massif is defined on the north and south respectively by these two zones of overfolding and thrusting which in both cases were at least partly brought about at the end of Jurassic time. If we adhere to the assumption that the movement came from the overthrust side and was directed as the overthrusts are, we shall arrive at the impossible conclusion that North China moved simultaneously both northward and southward. Recent observations in south-eastern Hupeh,[1] a district to the immediate south of the middle Tsin-ling, have shown that there, overfolding and overthrusting affecting the Jurassic coal-bearing series are systematically directed to the north. Here, then, we have an example of horizontal pressure being applied both from the north and the south, even if we assume that the overthrust side is the side whence the pressure originated.

The older exponents of the contraction theory may seize these facts as an argument in favour of their tenet; but apart from the inconceivable amount of radial shrinkage required to produce the horizontal shortening, such an argument would land us in an impossible position in explaining the peculiar arrangement of the aforesaid disturbed zones, their relation with the island arcs, and the mechanical processes that are involved in producing the several structural types to be described presently.

We may now conclude that the structures of the five zones referred to in the foregoing pages do not throw any light upon the direction of the movement of the continental masses involved. They, however, converge to show one thing definitely, that is the fact that Eastern Asia has been subjected to compression since very early geological time, and the compression is rendered particularly more explicit along the five west and east zones through overfolding and rupture of the strata.

The second group of predominant features of Eastern Asia is the array of tectonic mountains that run more or less parallel to the visible border of the continent. Space forbids us to inquire into the detailed structure of these mountains. We can here only note the mere fact of their existence with special reference to their trend, and their relation to the latitudinal zones as well as to the island arcs.

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[1] Li, C., "Geology of Puchi, Kiayu, etc.," *Mem. Inst. Geol.* (*National Research Institute of China*), No. III, 1928.

Starting from the north, the first range belonging to this group is the Aldanski, which borders the north-western coast of the Okhotsk Sea, and extends between the southern border of the Kolymski and the upper course of the River Uda. Geographically, this range may be regarded as the N.N.E. prolongation of the Stanovoi Mountains, but tectonically they are distinct.

The second range is the Great Khingan which separates Mongolia from Manchuria, and extends from the headwaters of the River Sungari to the S.S.W. until it meets the Inshan Range by describing a sweeping arc in its southern part. The Sikhota-alin is a range allied to the Great Khingan, but situated closer to the actual border of the continent. The tectonic features of the Sikhota-alin, unlike the gentler flexures of the Great Khingan, are of a rather violent type. Extensive overfolding and overthrusting inland have been observed in the southern part of the mountains. Jurassic strata are involved in the folding, which apparently took place towards the end of the Jurassic, and may have been repeated at a still later date.

The third range is the Taihangshan, along which the " tableland " of Shansi abruptly rises to a conspicuous height from the low plain of north-eastern China. Starting from western Chihli, this range runs at first in a S.S.W. direction ; but in its southern portion, it sweeps round towards the S.W., then W.S.W. in a grand curve, until finally it merges into the Tsinling. The eastern and south-eastern flank of this range is characterized sometimes by a monoclinal flexure, sometimes by normal faults, and occasionally by local thrust and overturned folds with their heads pointing towards the highland. Apart from the loess, the youngest strata known along the eastern and south-eastern flank of the Taihang are of Permo-Carboniferous age. They are all involved in the disturbance. The range was apparently developed at a much more recent date, which cannot yet be definitely fixed because of lack of direct stratigraphical evidence.

The fourth range extends from the Yangtze Gorges south-southwestward to form a watershed between the Provinces of Kweichou and Hunan. The southernmost part of this structural zone seems to merge into the Nanling Range on the northern border of Kwangsi. Here, according to K. L. Fong and T. C. Li,[1] the main range of the Nanling rises to a height of more than 1,200 m. accompanied by a large body of granitic intrusion, and intercepts a series of folds coming from the north-east or N.N.E.

From this brief account of the extension and trend of these four ranges several important points will be noticed. Firstly, from the Aldanski to the edge of the Kweichou Plateau, the four ranges are approximately, if not exactly, in line, and generally assume a S.S.W. trend—a fact already noticed by Richthofen in connection with the Great Khingan and the Taihang Ranges[1]; but he did not extend his inference further south and north. Secondly, these ranges are intercepted by the east and west zones of disturbance, so that, in their southern parts, they bend at first S.W., then W.S.W., until they apparently merge into the E.–W. zones; whereas in their northern parts such a bending effect is almost unnoticeable. Thirdly, these ranges are parallel to the island arcs, which are likewise intercepted by the E.–W. zones. Apart from the Aleutian arc, which is more closely connected with the North American Continent than with Eastern Asia, we find the first island arc formed by the Kurile Islands. This arc terminates at the southern apex of the triangular mass of Yezo Island, that is, at a point where the Inshan zone of disturbance terminates on the Pacific border. The second arc consists of Honshiu of the Japanese Islands. This again terminates on the south in the latitude of the Tsinling Range. The third arc comprises the Riukiu Islands which terminate on the south in the latitude of the Nanling Range. These facts are not mere coincidences but have a definite tectonic significance.

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[1] Manuscript.

In the Kurile Island arc, the curvature is fairly uniform all along its length; but in the Honshiu and the Riukiu arcs, it is in the southern part that the curve assumes a sharp bend. In the case of Honshiu, the bending takes such a sharp turn that it has given rise to a tract of extraordinarily intense disturbance known as the "Fossa Magna" in Central Honshiu and the Shichito line stretching into the Pacific. We see, then, that these island arcs repeat the form of the Great Khingan, the Taihang Range, and the edge of the Kweichou Plateau. These facts, together with the tectonic relation between these arcs and the latitudinal zones of disturbance, afford a clue for unravelling the direction of movement of Eastern Asia. In passing, we might note that the Okhotsk Sea, the Sea of Japan, the Yellow Sea, and the South China Sea are each but a part of a geosyncline on the border of Eastern Asia, not unlike the Appalachian geosyncline of eastern North America; but here it is developed on a grander scale, and came into existence at a much later date—probably since the end of the Jurassic or the Cretaceous. That it is an active geosyncline is indicated by numerous observed facts which unfortunately cannot be dealt with here because of lack of space. Towards the mainland of Eastern Asia we find a second geosyncline in the Valley of the Liaoho, the Gulf of Peichihli and a part of the Loess plain in north-eastern China. This second geosyncline is also of an active nature. It assumes the same trend as the outer one, but is developed to a lesser extent, though, in all probability, it originated in the same way and at about the same date. Manchuria and Shantung are parts of a geanticline which separates, though not completely, the inner geosyncline from the outer one.

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[1] Richthofen, F., *China*, vol. ii, pl. vi, 1882.

From these bordering features of Eastern Asia, it will be understood that the eastern border of the Asiatic continent has been subjected to compression since, at all events, late Mesozoic time. Moreover, the direction of the compression must be more or less perpendicular to the continental border. The question arises: whence originates such a compression? There are two possible answers. In the one, we may assume the foundering of the Pacific floor, which is the classical theory stoutly held by most American geologists. In the other, we may postulate that the Eastern Asiatic continent moved southward. In either case a pressure normal to the border of the continent would be developed. As far as the above described facts are concerned, there seems no firm ground on which we may make our choice. The fact that only in the southern parts of the island arcs, and their related ranges further inland, do we find a sharp bend, would seem to favour the postulate that the several altitudinal sections of Eastern Asia have moved southward, but have been more or less checked in the latitudes where the east and west zones are developed. This, however, does not afford a proof. More conclusive data must be found in the structural types to be dealt with below.

IV. STRUCTURAL TYPES IN EASTERN ASIA.

As already said, in distinguishing the structural types we must constantly pay attention to the genetic process or processes. Those which are generated by a single process belong to the unitary group; and those which are generated by two or more processes operating concurrently belong to the syntaxial group. Sometimes difficulties arise in differentiating these two groups. As a rule it will, however, be readily recognizable whether a given system falls in one or the other group. We will first of all deal with some examples belonging to the unitary group.

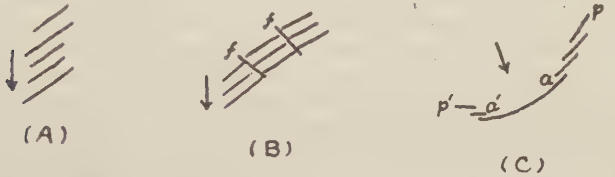
A. *Unitary Systems.*

(*a*) *ξ or xi Type.*—This type of structure refers to a horizontal sequence of folds with a persistent trend and with the individual folds arranged *en échelon* and more or less equidistantly spaced. When they traverse a large tract of a continent they usually run in a north-easterly or north-westerly direction. They are sometimes evenly spaced, with a strictly parallel arrangement, and sometimes highly compressed with a tendency to crowd together towards one end of the whole system. The former variety may be called *parallel ξ type*, and the latter, *convergent ξ type*. The trend of the parallel xi type generally varies to some slight extent according to the position where they occur. Within a given area, either the north-easterly or north-westerly strike is generally maintained. The two sets are rarely, if ever, found to occur together unless their date of formation is separated by a prolonged period of time.

The parallel variety usually occurs over a broad expanse of continent; while the convergent variety is generally restricted to a critical zone, for instance, along the border of some ancient massif or actually on the border of a continent. The two varieties may, of course, merge into each other. In the convergent variety, we can often distinguish the anterior and posterior ends of the folds. The convergent or more compressed end of the folds is defined to be the anterior and the less compressed or divergent end of the same folds is named the posterior end. The accompanying diagrams (Fig. 2) show the arrangement of the axes of folds in the two varieties of the xi type

When the parallel folds become highly compressed, they are often traversed by a series of dip faults (Fig. 2B).

A few actual examples will serve to illustrate the nature of this type of fold. It has been noticed for a long time that the Amphitheatre of Irkutsk has persisted throughout geological time as the nucleus of Eastern Asia. This idea is largely derived from the fact that from the interior of the amphitheatre waves of folds are propagated divergently to the south-westerly and south-easterly directions. To the south-west, or rather south-south-west, the north-westerly folds spread to a relatively limited extent. They are found in the East Sayan and the western part of the Khangai Mountains. Further south, their influence is only slightly felt in the eastern part of the Mongolian Altai; but down to the Nanshan Ranges, north-westerly folds again become a dominant feature. They crowd together along the north-eastern border of the Tarim Basin.



(A) (B) (C)

Fig. 2.—Different forms of xi structure. *A*, parallel xi type; *B*, parallel xi type with cross faults, *f*, *f*; *C*, convergent xi type; *a* and *a′*, anterior ends; *p* and *p′*, posterior ends; arrow indicates direction of principal movement.

On the south-eastern border of the amphitheatre, there occurs a series of compressed and overturned folds striking N.E. and running across Lake Baikal, hence the name Transbaikalia. The influence of this north-easterly folding is so powerful and widespread that its effect in determining the detailed plan of Eastern Asia can be traced from eastern Siberia down to the extreme south of China, not even excluding the island arcs. More than half a century ago, Pumpelly noticed the dominating influence of these north-easterly folds in Mongolia and North China, and styled them the "Sinian System of Folding". As the term Sinian has now won an established position in stratigraphy, the writer proposes to use the term, Sinoid, to designate this group of north-easterly folds. The newly proposed term seems all the more justifiable when it is remembered that from Transbaikalia to the southern limit of China, the north-easterly folds may have been locally brought about in very different ages.

Since Pumpelly's time, the importance of the Sinoid folds in the tectonics of Eastern Asia has become ever more evident as our knowledge widens out. Some confusion has, however, arisen through grouping together the true Sinoid folds with the N.N.E. flexures such as the Great Khingan, the Taihang Range, and the island arcs. The N.N.E. structural axes already referred to have nothing whatever to do with the Sinoid group. Their independent character is clearly shown by the disjunctive nature between the south-western continuation of the Stanovoi and the northern terminus of the Great Khingan, again by the irrelevance of the "Gridiron of Paking" to the northern Taihang Range, and finally by the north-easterly folds in south-eastern China which run obliquely into the coastal region, but not parallel to it.

According to Obrutschev, the Sayan and Transbaikalian trends that define the Amphitheatre of Irkutsk had already developed in Archaean time; for the upper part of the Archaean rocks exposed to the west of the lower Selenga strike N.W., whereas those to the east strike N.E. These two sets of strikes curve into each other along the southern one-fourth of the length of Lake Baikal.[1] At the end of the Eozoic or Algonkian Period, the borders of the amphitheatre were again strongly folded and thrust in the same Sayan and Transbaikalian trends.[2] The fact that Lower Palaeozoic strata developed in this region have not suffered the same intense folding enables Obrutschev to determine that the intense folding took place in pre-Cambrian time. Later foldings such as the Caledonian and Hercynian were essentially spread to the outer zones; in the inner, namely the border of the amphitheatre itself, igneous activity played a dominant rôle. Tetjajev [3] has, however, recently found in the Irkut and Kitoi districts, Cambrian and Pre-Cambrian strata thrust from the south-west over the coal-bearing series of the Irkutsk Basin. This shows that the post-Jurassic movement had affected the marginal zone of the amphitheatre in a way similar to what happened in Pre-Cambrian time.

In north-eastern and south-eastern China, where the Sinoid folds attain an extensive development, few stratigraphical data are yet available for determining the date or dates of the folding. In north-eastern China, the Shansi Series of Permo-Carboniferous age appears to be the youngest formation involved in the north-easterly folding.

[1] Obrutschev, W. A., op. cit., pp. 26, 411.
[2] Ibid., pp. 48–50, 412–13.
[3] *Isw. Geol. Komit.*, 1924, No. 2, p. 106.

From western Chekiang, C. C. Liu and Y. T. Chao[1] have recently reported that the Palaeozoic, including the Permian strata which are folded in the Sinoid trend, are unconformably overlain by the Kienteh Formation. The latter is, in turn, unconformably succeeded by a porphyry probably of Cretaceous age. The Kienteh with minute *Estheria* cannot be younger than Cretaceous. As far as our present knowledge goes, we may say then, that within the area of China Proper, the Sinoid type of folding assumed orogenic importance between the time limits of post-Palaeozoic and pre-Cretaceous. V. K. Ting has verbally informed the writer that he has quite lately observed in Kwangsi a folded and eroded coal-bearing series of Upper Carboniferous age discordantly overlaid by the *Verbeekina* Limestone of the Permian. In the western Tsinling Richthofen recorded an instance of stratigraphical discordance between the Permian limestone and its underlying Palaeozoic strata. In central and south-eastern China, although similar critical cases have not yet been discovered, there is little doubt that the Mesozoic is separated from the underlying Palaeozoic by a great unconformity. These facts afford positive evidence that South China fell in the domain of Hercynian folding. Evidence for post-Jurassic or Laramide movement has been brought forward from Siberia, Mongolia, northern, central, and south-eastern China, and has been already referred to in the foregoing pages. It remains to be noted that in China, while the Jurassic may locally assume a distinct trend, the Mesozoic taken as a whole, is folded much in the same way as the Palaeozoic; that is, folded after the Sinoid type. It is difficult to say whether or not the Sinoid type of folding recurred in post-Jurassic time. The fact that the Young Red Sandstones of Tertiary age so extensively distributed in South China are often tilted to the north-west or south-east would seem to suggest the affirmative.

We are thus enabled to see that the Sinoid type of folding has been brought about more than once, and that the earliest movement that gave rise to those folds probably dated back to Pre-Cambrian time. This is at least true in Transbaikalia. This remarkable fact indicates that the orogenic forces that operated in Eastern Asia in different geological times are essentially of a similar nature.

The Sinoid folds described above afford the best example of the parallel variety of the xi type. Examples of the convergent variety of the same type are found almost everywhere where the development of the parallel xi lines are arrested. They occur for instance, in Kamchatka, the Kuriles, the north-eastern part of Japan and the Riukiu Arc. A similar type of structure probably also occurs in the Marianne-Yap-Pelew island arc. In each of these island arcs there are apparently two groups of convergent xi lines; the dominant group is distributed in the north-eastern part of each arc with its anterior end pointing to the south or the south-west, and the minor group in the southern or south-western part of each arc with its anterior end pointing to the east or east-north-east. These facts have an important bearing upon the tectonic movements of Eastern Asia, and will be again referred to in our later discussion.

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[1] Liu, C. C., and Chao, Y. T., "Geology of Western Chekiang," *Bull. Geol. Surv. China*, No. 9.

EXPERIMENT I. (Pl. XV, Figs. 4–5.)

Place a hand flatly on the soaked paper already laid upon the polished board, and then apply a little tangential pressure or shear by the hand so as to cause that part of the paper on which the hand is placed to slide gently and uniformly in a definite direction. A series of parallel folds will then appear on each side of the hand; and the folds will be found to strike at about 45° to the direction in which the hand moved, provided that the movement is only carried to a moderate extent. The development of the folds is sometimes facilitated by placing one hand in a fixed position on the paper and shifting the other at some distance within the same sheet of paper. In this way, parallel folds striking at less than 45° to the direction of the movement can be produced. The more extensive the movement, the more crowded are the resulting folds. An individual fold may be juxtaposed by the following one, and fractures may appear in the direction perpendicular to the folds when the movement is carried to the extreme.

When the movement is not uniform, that is, when the movement is gradually being checked towards the anterior margin of the place on which the hand is placed, then, the resulting folds change their strike successively, with the result that a convergent xi type is produced. The anterior part of the system always points in the direction to which the paper is shifted. It is easily seen that this should be so; for in the posterior part the paper has a greater shearing displacement, and consequently the induced folds are dragged to a position such as to make an acuter angle with the direction of movement; while the anterior part, being held in check, may even develop a trend that approaches the direction normal to the direction of movement. In other words, the shearing stress is being gradually transformed into direct compression. (Pl. XV, Fig. 1, *ac*.)

(*b*) ν or *Nu Type.*—This type consists of a series of arcuate folds with their convex front persistently facing one side and with the individual folds converging towards some definite direction. The successive fold-arcs either virtually or actually meet at a number of points which are sometimes located more or less at random towards the convergent or anterior end of the system, and sometimes along an arcuate line with its convex front facing the same side as does the whole system. In the latter case, the successive arcs are arranged after the fashion of a broad spiral. The system then differs from the convergent xi type only in the individual folds having a larger curvature. In the posterior part of the system, or the part that is farthest removed from the convergent end, the successive arcs often appear nearly, but never exactly, concentric. As they are traced along one direction, they are invariably found either to approach, or to depart from, one another.

One of the finest examples of the nu type of folds is found in the central part of the Province of Hunan covering the districts of Luiyang, Yunghsin, Kweiyang, Pinhsien, and Kiaho. The geological structure of these districts was originally mapped by Richthofen[1] and more recently studied by S. Chu.[2] The tectonic outline of this area agrees almost completely with that represented in Fig. 3, B. The geological formations involved in the convergent arcuate folds are, according to Richthofen, a crystalline limestone, attributed to Lower Carboniferous, a Kohlenkalk probably of Permian age, and a coal-bearing series which either belong to the Permian or Jurassic or partly Permian and partly Jurassic. The anterior end of the system points to the south-west, that is, to the districts of Kiaho, Lanshan, and Linwu. The south-eastern border of the system is delimited by the porphyries of the Pauyunshan and Sankushan which also curve towards the south-west.

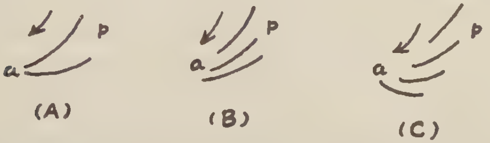

Fig. 3.—Different forms of nu structure. *A*, simple nu; *B*, ordinary nu type; *C*, spiral-like nu type; *a*, anterior end; *p*, posterior end; arrow indicates direction of principal movement.

Another example of this type occurs in the north-eastern part of Indo-China, to the north of Honoi. The dominant trend of that part of the country is indicated by the course of the Red River, namely, south-east. Around the eastern border of the Laokay-Backan massif, however, the trend of the structural axes varies considerably. On the north-eastern border of the massif they are approximately parallel to the course of the Red River; but from Caobang southward they are turned to the S.S.E. To the south-west of That-Khé, they sweep round to the south-west in the form of successive arcs.[3] The arcs are not concentric but tend to converge towards the neighbourhood of Thainguyen, that is, towards the south-west.

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[1] Richthofen, F., *Atlas von China*, Zweite Abt. Tafel 40.

[2] Chu, S., "Upper Palaeozoic Formations and Faunas of Yaoling, Chienhsien, S. Hunan," *Bull Geol. Soc. China*, vol. vii, No. 1, 1928, pp. 61–75.

[3] Zeil, G., "Contribution à la géographie tectonique du Haut-Tonkin," *Ann. de Géogr.*, xvi, 1907, pp. 430–50.

A third example is found in the island groups of the Sulu Sea and north-western Borneo. In the area of the Sulu Sea, G. F. Becker[1] recognized three structural lines which are classed as the "Inner Series". The northernmost of these lines forms the axis of Palawan; the next one to the south-east starts from the north-western part of Panay Island, and extends into the middle part of the north-eastern coast of Borneo; the southernmost one follows the array of the Sulu Archipelago. Each of these lines describes an arcuate path with its convex front facing the south-east; and they tend to approach one another as they proceed towards the north-eastern coast of Borneo. In the north-western part of Borneo, we find the high range of Kapoewas extending from Kini Bulu to Cape Tatu, and forming a sweeping arc, again with its convex front facing the south-east. Although it is difficult to make out any characteristic feature from the earlier observations in the neighbourhood of this range as summarized by Suess,[2] yet in the tectonic map constructed by H. A. Brouwer embodying the most up to date results,[3] the spiral-like arrangement of the predominant tectonic lines is revealed with remarkable lucidity. It may be gathered from Brouwer's map that here the convex front of the arcs at first faces the south-east; but as they proceed westward, the convex side is turned towards the south, and then south-west. Consequently the anterior end of the system points at first towards the south-west, then changes towards the west, and finally towards W.N.W. or even N.W., with a tendency to adapt itself to the trend of the Natuna Islands.

It is to be noted that in all these three cases, the more or less eccentrically arranged fold-arcs start from the north-east, and gradually sweep round and at the same time approach one another towards the south-west, west, or even W.N.W. In the southernmost example, the bending effect becomes more pronounced. This latter fact has a profound meaning, and will be referred to when we come to discuss the movement of Eastern Asia.

EXPERIMENT II. (Pl. XV, Fig. 6, Pl. XVI, Fig. 6, Pl. XVII, Figs. 1, 2.)

Place the ball of the thumb of the left hand on the soaked paper laid upon the polished board, and press the paper more or less firmly; then give the thumb a slight movement towards the body and at the same time twist it clockwise. Folds of nu type will be made to appear with the anterior end of the system pointing to the direction of the twisting movement. The greater the twisting movement, the more pronounced will be the bending effect of the fold-arcs. The development of nu folds is therefore clearly due to torsional shear.

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[1] Becker, G. F., "Report on the Geology of the Philippine Islands," *U.S. Geol. Surv. 21st Rep.*, 3, 1901, pp. 493–614.

[2] Suess, E., *La Face de la Terre*, tome iii, 1re partie, pp. 305–8, 322–39.

[3] Brouwer, H. A., "The Major Tectonic Features of Dutch East Indies," *Journ. Ac. Sc. Washington*, 1922.

(*c*) *ν-Δ or Nu-delta Type.*—This is a highly specialized type of the nu folds. So far, only two examples are found in Eastern Asia; and it is not probable that this type occurs elsewhere on the globe. The one is the Kuriles-Sakhalin-Yezo system, and the other is the Formosa-Luzon-Palawan-Borneo-Pelew-Yap-Marianne system. This type of structure consists of two arms arranged after the fashion of the Greek letter, ν, with a triangular land-mass attached to its vertex. The axes of the folds in the inner arm are almost straight or only slightly curved, and generally run in the meridional direction; while the folds or fractures in the outer arm are of the xi type, and describe, as a whole, a greater curvature. The whole system recalls strongly some form of *Didymograptus* with its two stipes meeting at an angle less than 50° and with its sicula—here the triangular mass—pointing to the distal end. The triangular mass generally possesses some arcuate structural lines extending between, or connecting with, the two arms. The concave side of these arcuate structural lines faces the open end of the two arms or the proximal end of the system.

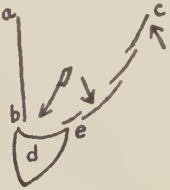

FIG. 4.—Nu-delta type of structure. *ab*, inner arm; *ce*, outer arm; *d*, delta-like mass; tailed arrow indicates principal movement; plain arrows indicate the directions of pressure aroused by the principal movement.

It is beyond any doubt that the island of Yezo or Hokkaido is tectonically connected with Sakhalin on the one hand and the Kurile Islands on the other.[1] Beginning at the north-east we see quite obviously that the volcanic zone of the Kuriles runs into the island of Yezo for a considerable distance until it becomes split into two branches: the one bends around towards the north-west so as to adapt itself to the trend of the Hidaka Range, and the other continues to extend south-westward until it strikes against the same range at an angle of about 90°. The tectonic connection between Yezo and Sakhalin is still more obvious. The Hidaka Range which runs across the island of Yezo from Cape Yerimo on the south to Cape Soya on the north, is apparently cut off by La Perouse Strait; but in fact it reappears at the southern extremity of Sakhalin; thence northward, the same range—here known as the Principal Chain of Sakhalin—continues to run meridionally for more than two-thirds of the whole length of Sakhalin. To the east of the Principal Chain more meridional ranges appear. The northernmost of these subsidiary ranges is known as the Tym Mountain which turns slightly west as it extends northward. From Cape Dui northward, both the Principal Chain and the Tym Mountain seem to broaden out so as to form a plateau-like country in the area of Engys Pal. The strata are, however, by no means flat, but folded meridionally.

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[1] Suess, E., *La Face de la Terre*, tome iii, pp. 175–86.

Cretaceous strata ranging upward from the Cenomanian stage are widely distributed in Yezo and Sakhalin. They are clearly involved in the meridional folding. Tertiary deposits also occur in these islands, but according to A. Kryshtofovich, they occupy a far less extensive area than was formerly believed. In Russian Sakhalin, Kryshtofovich distinguishes two series of Tertiary formation: The Lower Tertiary or the Dui Series, consists of coal-bearing sandstones, shales and conglomerates, and unconformably overlies the Cretaceous on the sea coast close to the village of Mgach. Elsewhere, however, the Cretaceous seems to pass into the Tertiary without pronounced difference of dip. The Upper Tertiary, or the Mgach Series, chiefly consists of rather loose sandstones and shales with some coals in its lower part. Although the stratigraphical relation between the Upper and the Lower Tertiaries is not yet clearly understood, the fact is already established that the Upper Series often rests directly upon the Cretaceous, being itself only slightly disturbed.

In the north-eastern corner of Yezo and on the island of Shikotan, which is closely associated with the Kuriles, Cretaceous deposits occur. And on Shikotan Island andesitic ejectamenta are found in the Cretaceous sediments. Thus it would appear that the whole system was mainly brought about probably by an infra-Cretaceous, as well as the Laramide movement, and may have been accentuated by movements in Tertiary times.

The Formosa-Luzon-Palawan-Borneo-Pelew-Yap-Marianne system is essentially similar to that of Sakhalin-Yezo-Kuriles. There is little doubt that they both belong to the same type. Using the Sakhalin-Yezo-Kuriles system as the standard type, we will now proceed to compare the two systems, and note the minor variation in the southern system arising from more complex circumstances. The inner arm of this system consists of the disconnected series of islands, Formosa, Bashee, Babuyan, Luzon, and Palawan. The outer arm embraces the Marianne or Ladrone group, the Yap Islands, Pelew, Tulur and the northern arm of Celebes. Much remains to be studied in the detailed structure and arrangement of the Islands that make up these two arms. So far as our present knowledge goes, there cannot be much doubt that the visible elements in the inner arm are arranged in line, though their tectonic axes may vary locally. Those in the outer arm are, in all probability, not simple xi lines, but consist of at least two classes of features; one originates from tension and the other from compression. The latter must be largely responsible for the general array of the island masses as well as the northern arm of Celebes. It is chiefly because of the interruption of the powerful Sangir line coming down from Mindanao and the existence of the rather deep strait of Macassar, that the northern arm of Celebes is not usually considered as a part of the Marianne Kaniongan Arc.

Granting this tectonic interpretation, the inner arm then compares favourably with Sakhalin, and the outer with the Kurile Islands. The remaining mass of the system, namely Borneo, would then correspond to Yezo. Here the shape of the pendent mass is likewise approximately triangular. One would not be tempted to make this far-reaching comparison, had it not been for experimental evidence.

The notable difference between this system and the northern one lies in the fact that not only is the outer arm bent to a greater extent, but the inner one also describes a broad arc. The arcuate effect becomes more pronounced as the pair of arcs stretch and converge towards the south-west. As far as the two arms are concerned, they constitute a true nu type of structure on a grand scale. Another modified feature arises from the existence of the Cordilleras of the Philippine Islands. They, together with their westerly virgations, constitute a new type which will be dealt with separately. The third point of difference is the shape and structure of southern Borneo, which cannot be strictly compared with southern Yezo. This modification will be made evident when we come to consider the movements of Eastern Asia.

From the stratigraphical evidence so far obtained from the Philippine Islands, it appears that a strong orogenic movement took place in this region in post-Cebúan or post-Eocene time. But the whole system probably had its origin long before that date—Cretaceous or even earlier.

EXPERIMENT III. (Pl. XVI, Fig. 3.)

Place the two hands in a parallel position, and leave a narrow space between them. Shift the left hand inward and at the same time sideways, when a series of xi folds will appear. Then place one or two fingers of the left hand near the lower end of the xi folds and hold them firmly, while at the same time the right hand is placed on the upper end of the xi folds in a position more or less perpendicular to the xi series. While keeping the fingers of the left hand in position, the right hand is pushed towards the left. In the meantime the two arms of the system will appear in the shape of an asymmetric V. If the left hand is slowly rotated clockwise and at the same time pulled sideways and inwards, then the two arms of the V will become curved with their convex front facing the right-hand side. The greater the amount of pulling and twisting, applied by the left hand, the larger is the curvature of the resulting V.

Now take off the hands, and allow a little air to get into the space below the paper where the left hand exerted its movement. Here a striking thing happens. The air will be seen to collect itself together so as to form a triangular projection above the rest of the paper. The writer has observed this singular phenomenon nearly every time the experiment was repeated. There cannot be any question of chance. The paper must have been strained in that way. This accidental discovery not only throws light upon the origin of the Yezo and Borneo masses, but also demonstrates that the two nu-delta systems discussed above really belong to one type.

(*d*) η or *Eta Type.*—This type of structure consists of an almost semicircular arc succeeded at one end by a series of convergent xi lines, whose anterior end either points away from, or towards the convex front of the arc. There may be several arcs in the system. The inner ones, or the cranium of the system, are generally more or less concentrically disposed. The outer ones, or the crown of the system, usually follow the shape of the mass which they envelope, and form a receding succession of arcs as they propagate outward. Cranial arcs are always deeply incurved, and are of relatively small dimensions as compared with the size of the whole system. The individual crowning arcs usually occupy but a small sector of a circle. Very rarely, if ever, do they arrange themselves on one and the same circle. The intensely disturbed part of the limb of the system, is always attached to the cranium. It may consist of a single row of xi lines or may embrace a bundle of crowded folds, faults, or even thrusts.

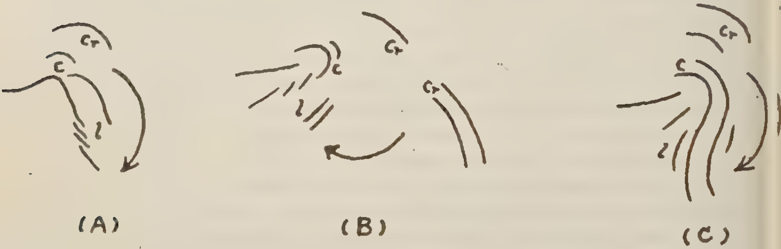

Fig. 5.—Different forms of eta structure. *A* and *C*, elongate form ; *B*, broad form ; *c*, cranium ; *cr*, crown ; *l*, limb ; arrow indicates direction of torsional movement.

Only two examples of the eta type are found in Eastern Asia, although elsewhere in the world this type occupies a prominent position, and affords an important clue for detecting continental movements. The standard type is found in the south-eastern corner of Asia, that is, in the island groups of the Banda Sea. Here, the innermost element of the system consists of a group of small islands : Ombay, Wetter, Serwati and a number of others. These islands are so arranged that they form almost a complete circle or a loop. Starting from the Flores we can trace them around until we come back to the island of Gunong Api. The second element starts from Buru passing eastward along Ceram, then southward through the Key Islands and finally south-westward through the Tenimbers. In this second element the arc is almost exactly semi-circular, and probably terminates in the Tenimbers. Both Suess[1] and Brouwer[2] would carry this line further west by assuming that it passes through Babber and Timor. This interpretation seems, however, to be based on a broad generalization, not on detailed structure. Brouwer himself has instructively indicated a north-easterly trend on the Babber Island and east-north-easterly trend on Timor. There are no available data for determining the trend of the small islands dotted between Timor and Babber. Nevertheless, if we compare the known structures of the Tenimbers, Babber, and Timor, it seems quite clear that these islands are, in fact, arranged *en échelon*. Thus we are able to locate the xi lines in the system. Aru Island undoubtedly represents a fragment of a still outer arc.

The system is, however, not complete within these island groups. What we see here is that part of the whole system which suffered the most powerful bending and turning, namely, a part of the limb and its cranium. To accomplish such a powerful bending and turning, there must be related features of similar type to indicate that cause. We find nothing of the kind to the north of the Banda Sea, but we find them in, and more especially around, the gigantic mass of Australia. The Kimberley Mountains of north-western Australia add a part to the complete view of the limb, and New Guinea together with the Australasian and Micronesian festoons of Gregory demonstrate the grandeur of the crowning arcs of the system.

The second example is found to the south-east of the Tibetan massif. Here the structure is still poorly known. But from the observations made by various travellers we gather that the high ranges that lead to the sources of the Salween, Mekong and Yangtze are all incurved into the Tibetan Plateau forming a succession of arcs with their convex fronts facing the north-east. Coming southward, a bifurcation of structural lines appears to have taken place between Talifu and Yunchangfu. One of the branches proceeds steadily towards the south-east, but the other runs almost meridionally between the Mekong and the Irrawadi. Farther west, this western branch gradually turns towards the south-west above latitude 24° N. Going north-westward, we come across the Patkoi and Zayul Mountains before the eastern terminus of the Himalaya is reached. The axes of these pre-Himalayan ranges apparently vary from north-east to east-north-east. Cretaceous probably as well as some Tertiary strata are involved in the folding.[3]

Extremely fragmentary as our knowledge is, it enables us to recognize the essential characteristics of the eta type. In the embracing heights around the elbow of the Brahmaputra we see the cranium of the system ; in the north-easterly folds of the Patkoi and those of northern Shan States we find the limb ; and lastly, in the *Faisceau du Mékong* the crown of the system is developed *par excellence.*

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[1] Suess, E., *La Face de la Terre*, tome iii, p. 307, fig. 43.

[2] Brouwer, H. A., op. cit.

[3] Suess, E., op cit., pp. 275–87.

(*To be continued.*)

EXPLANATION OF PLATES XV–XVII.

Plate XV.

Fig. 1.—A broad type of epsilon structure induced in the middle part of the paper by placing a finger at *A* and shifting the pressed part of the paper in the direction indicated by the arrow. *x y*, axis ; *a*, apex ; *a b*, left wing ; *a c*, right wing. Both wings are only slightly turned forward towards their terminal parts. Compare this form with the Eurasian Epsilon.

Fig. 2.—A highly compressed type of epsilon structure induced in the upper part of the paper by shifting it at *A* in the direction indicated by the arrow. *x y*, axis ; *a*, apex ; *a b c*, left wing ; *a d*, right wing ; *p* and *q*, two small reflex epsilons. This type strongly recalls the structure of the Epsilon of Irkutsk : *c*, comparable with Sailiugem ; *b*, with Sayan ; *d*, with Vitim Plateau.

Fig. 3.—A broad epsilon similar to Fig. 1, purporting to represent the Amazon-Andean Epsilon.

Fig. 4.—Two groups of parallel xi structure : *a b*, normal type ; *c d*, with cross faults, $f f$, $f_1 f_1$, $f_2 f_2$, $f_3 f_3$, $f_4 f_4$. Arrows indicate directions of movements. Compare this type of structure with that of the western Harz.

Fig. 5.—Convergent xi type of structure with the individual folds tending to converge towards the left-lower end of the system. Arrow indicates the direction of movement. Compare this type of structure with the north-eastern parts of the Kamchatka-Kurile and Riukiu Arcs.

Fig. 6.—A nu type of structure with a series of highly compressed xi folds. Arrows indicate the directions of movement.

Plate XVI.

Fig. 1.—A geniculate type of structure formed through lateral contact of two epsilons. Arrows indicate the directions of movement. Note the absence of axial folds on the concave side of the geniculate curves. Compare this type of structure with that of the Poonch State and its adjacent districts.

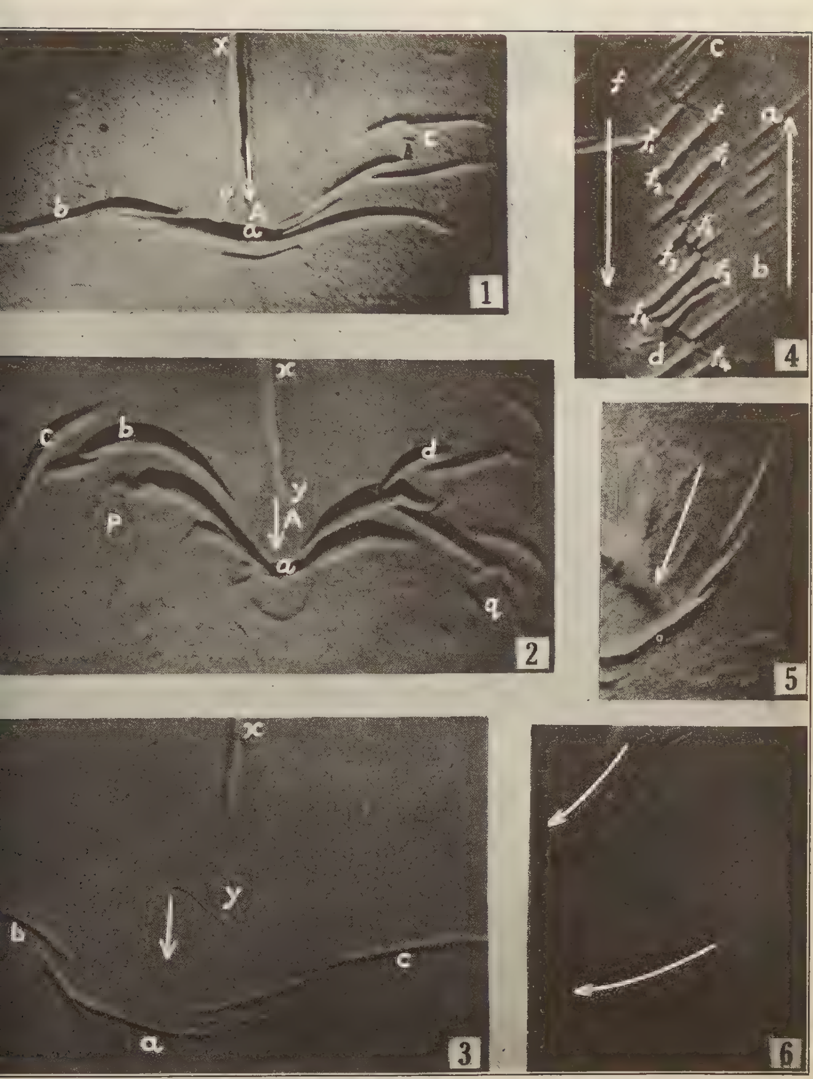
Fig. 2.—A normal lambda type of structure, *a*, *b*, dominant limb ; *c*, *d*, *e*, *f*, *g*, *h*, subordinate limb. Arrows indicate the directions of movement. Compare this type of structure with that of the Philippine Islands.

Fig. 3.—A nu-delta type of structure purporting to represent the Sakhalin-Yezo-Kuriles and Formosa-Luzon-Borneo-Pelew-Marianne Systems. Arrows indicate the directions along which pressures were simultaneously applied. In the case of the actual examples—the Sakhalin-Yezo-Kuriles and Formosa-Luzon-Borneo-Pelew-Marianne Systems—the lateral pressure required to produce the system was probably induced by the southerly or south-westerly movement of the continental border.

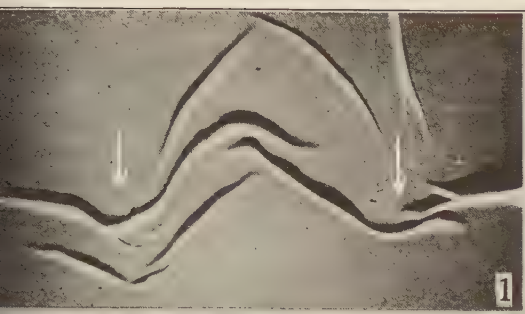
Fig. 4.—An eta type of structure produced by turning the paper as indicated by the arrow. *aa*, *bb*, *cc*, cranium ; *ee*, crown ; *ff*, limb. If the space between *ff* and *cc*, *ee*, be broadened, then the latter become comparable with the Australasian and Micronesian festoons.

Fig. 5.—A part of the eta type. *a b*, *c d*, cranium ; *b e*, limb. This figure is produced by tightly pressing down the space, *A B*, and turning the paper in the way indicated by the arrow.

Fig. 6.—A nu type of structure produced simply by turning the paper in the way indicated by the arrow.



Experimental Production of Structural Types: I.



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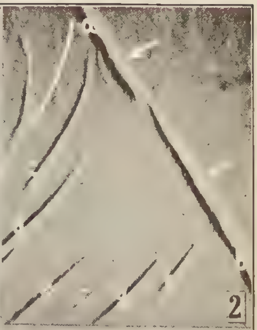

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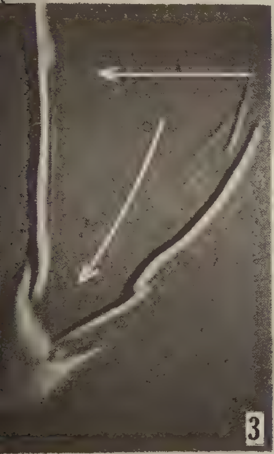

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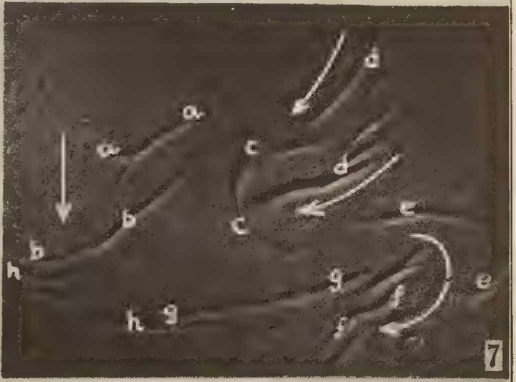

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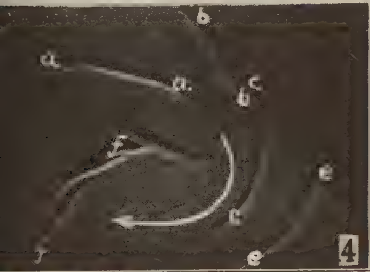

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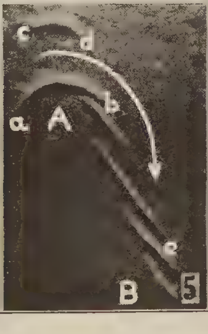

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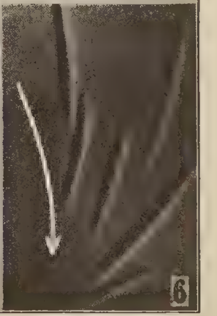
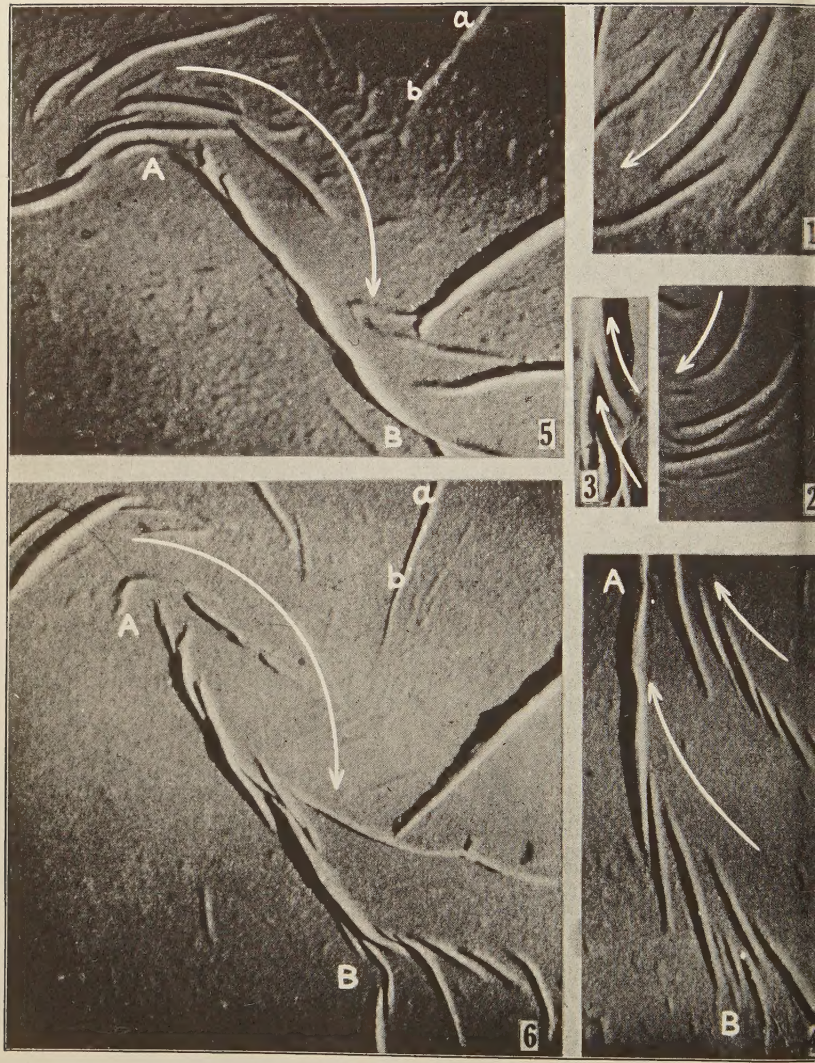


6

EXPERIMENTAL PRODUCTION OF STRUCTURAL TYPES: II.



Experimental Production of Structural Types: III.

Fig. 7.—A synthetic attempt to reproduce the major structural lines of the Philippine and East Indian Islands. Compare with Fig. 1 *aa*, Kapoewas; *bb*, Banka and south-western Borneo; *cc*, eastern Borneo and Celebes; *dd*, south-western part of Philippine Islands; *ee*, Banda Arc; *ff*, Timor; *gg*, Java-Flores; *hh*, south-eastern Sumatra. Arrows indicate the directions of movement applied. Note that *hh* does not exactly agree with the structure of south-eastern Sumatra; for, there, the actual structure is of the lambda type and not simple xi, as indicated in this figure. This is due to the fact that no torsional movement was applied to that part of the paper which corresponds to south-western Borneo.

Plate XVII.

Figs. 1, 2.—Two forms of nu structure produced by turning the paper in the way indicated by the arrows.

Figs. 3, 4.—Two similar forms of the reversed lambda type of structure, produced by turning the right portion of the paper against its left portion, which is firmly pressed down at *A B* in Fig. 4. Arrows indicate the directions in which the paper was twisted.

Figs. 5, 6.—Two examples of the eta structure with some accompanying features purporting to represent the major structures of North America. All the folds except *a b* in these two figures were produced by a single process, namely, by pressing the paper down at *A* and *B* with two fingers of the left hand, and applying the whole of the right palm to the right side of a line drawn from *A* to *B* with an effort to shift the paper downward and at the same time to turn it clockwise. To facilitate the rotational movement the right upper corner of the paper should be removed beforehand. The fold, *a b*, was subsequently induced by shifting the paper locally towards its right lower side. The fact that such a fold could be produced on the already highly strained paper without disturbing the existing features suggests the probability that the United States Mountains were produced through the same process.

REVIEWS.

Oeuvres Géologiques de Marcel Bertrand. Edited by Emm. de Margerie, and published under the auspices of the Académie des Sciences. Vol. II, pp. xvi + 686, with 185 text-figures and 17 plates. Paris: Dunod, 1928.

The first volume of the collected works of Marcel Bertrand was reviewed in the Geological Magazine last October (p. 474), and the second volume has since appeared. It is divided into two sections, the first dealing with the French and Swiss Alps, and the second with the Paris Basin and the north of France. The first section includes the well-known series of studies in the French Alps and many other shorter contributions to Alpine geology. In the second section the highly original paper on the continuity of folding in the Paris Basin, and in southern England also, is one of the most interesting to English geologists; and the remarkable elucidation of the structure of the Franco-Belgian coalfield ought to be familiar to all our workers on Hercynian folds.

The name of Emm. de Margerie is a sufficient guarantee that the work of editing has been carried out with the greatest care and accuracy, and that the volume is all that the most fastidious could desire. Four of the plates are in colour.

P. L.

GEOLOGIC THERMOMETRY. By N. L. BOWEN. Reprinted from *The Laboratory Investigation of Ores*, edited by E. E. Fairbanks. McGraw-Hill Book Co., Inc., 1928.

SINCE this pamphlet is a reprint of a chapter from a book, it does not contain original work, but affords a useful summary of our knowledge of its subject, to a large extent in connection with ore-deposits. The author adds in a footnote that it has not been possible to include anything later than 1926. A brief summary is given of the means available for fixing points of temperature in igneous rocks and other deposits, and there is a useful table of the melting-points of twenty important minerals, including both silicates and sulphides. The subject of inversion-points is fully considered, and it is concluded that the earlier minerals of the more basic rocks freeze above 870° ; the principal crystallization of most rocks comes between 870° and 600°, while many pegmatites and segregations rich in volatiles solidify about 573°, while veins and replacements are formed from this point nearly down to the ordinary temperature. Little reliance is placed on the conclusions that have been drawn from the study of liquid inclusions in crystals. The temperatures of metamorphism and metasomatism show a very wide range indeed, occasionally rising to fusion point in thermal metamorphism, but generally below 870°. The dissociation of carbonates in metamorphism is also briefly discussed.

R. H. R.

OBITUARY.

Sir E. Ray Lankester.

The death of Sir E. Ray Lankester, the eminent comparative anatomist, deprives us of one who did much for the advancement of geology, especially on the palaeontological side. His work was largely carried out in his early years, and at the time of his death he was the sole survivor of the contributors to the first volume of this Magazine, which began to appear in 1864. In his declining years his interest in the subject was re-awakened by the discoveries relating to Early Man made in East Anglia, and he entered eagerly into the controversy that arose concerning the occurrence of artefacts in the Pliocene beds, contributing a paper to the Royal Society on what he termed " rostro-carinate " implements.